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ESSENTIALS OF ELECTRICITY

ESSENTIALS OF ELECTRICITY

A TEXTBOOK FOR

WIREMEN

AND THE ELECTRICAL TRADES

DIRECT CURRENTS

BY

W. H. TIMBIE

PROFESSOR OF ELECTRICAL ENGINEERING AND INDUSTRIAL PRACTICE,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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PREFACE

THE following brief text was developed from notes which the author has been using in short trade courses for students who wish to enter or to advance themselves in one or another of the electrical trades. It attempts to explain the underlying facts and laws of good electrical practice, which the really well-informed and efficient workman must understand, rather than to provide book descriptions of the mechanical operations of the electrical trades, which can be really learned only through continued practice in their performance. It is designed to be a systematized text for class and self-instruction, and, also, a book of electrical information to which frequent reference may be made during the day's work. For convenience in the latter purpose, it is bound in a pocket size and with semiflexible covers.

As is implied in the title, only such material has been included in the text as is regarded to be absolutely essential to the object in view. The order in which the various topics are taken up is that which the author has found to be most teachable. The method of presentation is designed both to arouse and hold interest, and to furnish the easiest approach to new or more difficult ideas. Foi this reason, the author's plan is to build outward, and by very small steps, from the starting point of the reader's own experience in the commercial shop or the school laboratory. Students in short trade courses must acquire a large fund of information in an extremely short time. This cannot be accomplished by increasing the size of the mental steps

the student must take, but rather by shortening and by properly arranging these steps, until he can pass most surely and rapidly from one conception to the next in order. In this connection, the numerous simple diagrams and the large number of direct and practical problems to be found in the book will prove most helpful.

In conclusion, I wish to take this opportunity to express my appreciation and thanks to Mr. Arthur L. Williston, Principal of Wentworth Institute, and Mr. J. M. Jameson, Pratt Institute, for the incentive and valuable aid which they have rendered throughout the preparation of this text. Grateful acknowledgement is also extended to my colleagues, Prof. H. H. Higbie and Mr. W. J. Mayo, for many valuable criticisms and suggestions.

W. H. TIMBIE.

NEWTONVILLE, MASS.,
November, 1912.

EDITOR'S NOTE

THE fundamental requisites for a really good textbook in any applied subject, or for a really good reference book for self-instruction, are: first, that it shall contain all of the more important facts and principles required by its readers; and second, that this information and theory shall be presented clearly and forcibly, unclouded by a mass of irrelevant matter. The strength of this short text lies in the satisfactory manner in which it meets both of these conditions. It is a book which supplies the underlying reasons, the "whys" of his task, which constantly present themselves to the intelligent "man on the job."

Mr. Timbie was selected to write the text of the Technical Series designed for the use of men in the electrical contracting business and allied electrical trades, not merely because of his intimate knowledge of industrial electricity, but also because of his well-known ability to present information in an unusually clean-cut and effective way. Those who are familiar with the "Elements of Electricity" by the same author have recognized this gift for clear and convincing expression. This more applied text is put forth with the belief that it will prove equally successful in its particular field.

THE EDITOR.

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ESSENTIALS OF ELECTRICITY

CHAPTER I

OHM'S LAW

1. The Flow of Electricity. Electricity, **in motion,** lights lamps, drives motors, refines metals, raises to a high temperature all sorts of electrical heating devices, energizes the telephone, telegraph and electric bell. Electricity, **at rest,** has few effects of practical value.

Accordingly, we are going to study electricity only as it moves, that is, flows and does work. Our purpose is to become familiar with the laws governing the effects and applications of electricity, rather than with its nature. We do not know what it is, but we may know many things that it will do.

Throughout our study, then, we must remember that we are concerned always with something flowing along a conductor, and not with something stored up in a tank. We, therefore, are concerned not with quantities of electricity but with **currents, or flow of electricity.** The sooner we become familiar with the idea of the flow, the sooner will we get a firm grasp of the subject.

We have to consider, then, three things:

(*a*) Current (the flow of electricity along a conductor).

(*b*) Pressure (that which causes the current to flow).

(*c*) Resistance (that which regulates the flow of current).

We are all more or less familiar with the flow of water through pipes and the simple facts governing this flow. Ac-

cordingly, we can help to make real our knowledge of the flow of electric currents along conductors by calling to mind the many points of resemblance to the flow of water.

2. (a) Current. Ampere. In the first place, when water is flowing through a pipe we never ask, "How much water is there in the pipe?" but rather, "How much current is flowing through the pipe?" That is "How much water flows through the pipe in a given time?" The answer would not be "Five gallons," but "Five gallons per second." We are interested not in quantity, but in **quantity that passes through in a second.**

Similarly, we never ask, "How much electricity is there in that wire?" but rather, "How much current is flowing along that wire?" By which question we mean, "How much electricity flows along that wire per second?" The answer could not be "Five coulombs," but it might be "Five coulombs per second." We are interested not in the quantity, but in the **quantity that passes in a second.**

Now a coulomb of electricity is just as definite a quantity of electricity, as a gallon is a definite quantity of water, coulomb being the name given to the unit in which quantity of electricity is measured.

But we are fortunate in not having to use the term "coulomb per second" to denote quantity of electricity that flows per second. We call this "coulomb per second" an **ampere.** Instead, therefore, of answering the above question by, "Five coulombs per second," we would say, "Five amperes." Thus we do not need to say "per second" each time, as "amperes" means "coulombs per second." So ten amperes means ten coulombs per second, etc.

Since we are always concerned with the flow of electricity and not the quantity, we employ continually the term **ampere** and rarely use the term **coulomb.**

Thus an ordinary 16-candle-power incandescent lamp, with a carbon filament, when burning on a 110-volt line, takes $\frac{1}{2}$ ampere; that is, $\frac{1}{2}$ ampere of current is flowing through it all the time it is glowing. A tungsten lamp of the same rating takes about $\frac{1}{4}$ ampere when glowing. A street arc lamp takes from 5 to 10 amperes according to the size and style.

It is unfortunate that we have no name for the unit flow of water, which means one gallon per second. Consequently we always have to say five gallons per second, ten gallons per second, etc.

3. (b) Pressure (that which causes a current to flow). **Volt.**

When a current of water flows through a pipe, we know that it flows because there is some pressure exerted on it, which causes it to flow. We say that in certain parts of the town the water comes to the houses under a pressure of 30 lbs. per sq. in. If one happens to live near the reservoir or pumping station, the pressure is likely to be higher than that at some distant point.

Similarly, when an electric current flows along a conductor, we know that it is caused to flow by some **electric pressure.** If we live near the generating station the pressure is likely to be higher than if we live at some distance. Thus the current through an incandescent lamp is made to flow by maintaining a pressure across the lamp. Ordinarily this is about 110 **volts.** When the lamp is turned on, it simply means that this pressure is allowed to act and force the $\frac{1}{2}$ ampere of current through the carbon filament of the lamp, — just as turning on the valve allows the 30 lbs. per sq. in. pressure to act and to force $\frac{1}{2}$ gallon per second through a water pipe. The 110 volts electric pressure does exactly the same thing to the electric current that the 30 lbs. per sq. in. water pressure does to the current

of water. Just as the **pounds per square inch** (pressure) cause the gallons per second to flow, so the **volts** (pressure) cause the amperes (current) to flow.

It is essential to get the idea of **amperes** as current and **volts** as pressure clear at the very start. We can then avoid such mistakes as the following: When the statement is made, that across the terminals of a switch there are 110 volts, we often hear an uninformed person ask, "How

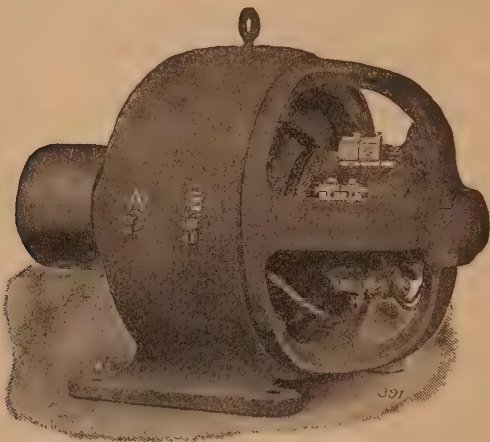


FIG. 1. Crocker-Wheeler direct-current generator.

many amperes are there?" If the switch is thrown off, there isn't any current flowing and of course there are no amperes, any more than there would be a current flowing in a pipe if the valve were turned off, even though the pressure were 100 lbs. per sq. in. If we were told that there were 100 lbs. per sq. in. pressure in a pipe we would not ask how much current flows, knowing well that it depends on whether or not we turn on the valve. Even then the current depends upon what is connected in the pipe line. So in an electric circuit, even if the volts pressure is known, the

current depends upon whether or not the switch is thrown on, and then also upon what is connected in the line for the current to flow through.

In Fig. 1 there are 110 volts pressure across the terminals *A–B*. There may or there may not be any current flowing to and from these terminals. The pressure is maintained as long as the machine is running, so that a current may be drawn from the machine if desired.

Again, we read in newspaper accounts of an accident, that a man was injured by so many volts passing through his body. This is not so. The volts merely caused a certain current (amperes) to flow through the person's body and this current injured the man. We might as well have said that so many pounds per square inch passed through him, as to say so many volts went through him. These examples are given in order that the student may, at the very outset, get a clear understanding of the meaning of volt and ampere and may avoid an incorrect use of them.

4. (c) Resistance (that which regulates the current). **Ohm.**

We have seen that if we put an incandescent lamp with a carbon filament on a circuit where the pressure is 110 volts, about $\frac{1}{2}$ ampere flows through the lamp. If, however, we place a tungsten lamp on the same circuit, the 110 volts pressure is able to force only $\frac{1}{4}$ ampere through the filament. We explain this by saying that the **resistance** of the tungsten filament is greater than the resistance of the carbon filament, and, therefore, allows the pressure to force less current through it. Resistance may then be defined as the property of a body which resists or limits the flow of electricity through it. It is similar to the friction in a pipe.

When a **pressure** of 1 volt can force 1 ampere of **current** through a wire, we say that the **resistance** of the wire is

1 ohm. If 1 volt can force only $\frac{1}{2}$ an ampere through a wire, we say that the resistance is 2 ohms. In order to force 1 ampere through 2 ohms resistance, it would be necessary to apply 2 volts pressure.

This agrees with what we know about the flow of water through pipes. If the pipe is small and rough, we know that it offers a large resistance to the flow of water through it, and a high pressure is necessary to force much current through it.

Similarly, if a wire is small and ill-suited for carrying an electric current, we find that its resistance is large, and that a great pressure (volts) is needed to force much current (amperes) through it.

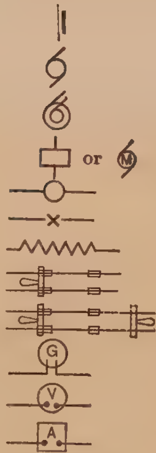
The following table will aid in fixing the meaning of the three terms discussed above. The student should study this table until thoroughly familiar with the meaning of the terms amperes, volts and ohms.

Units of	Water	Electricity
Quantity	Gallon	Coulomb
Current Quantity per second	**Gallon per second**	**Ampere** Coulomb per second
Pressure	**Pound per sq. in.**	**Volt**
Resistance	**No Unit**	**Ohm**

5. Symbols. In representing the different parts of an electric circuit it is customary to use certain symbols to indicate certain electrical pieces, as for instance -×- represents an arc lamp and  represents a direct-current generator. The following table contains the more common symbols used in this text.

SYMBOLS

Battery cell,
Generator, d-c.,
Generator, a-c.,
Motor,
Incandescent lamp,
Arc lamp,
Resistance,
Switch — single-throw,
Switch — double-throw,
Galvanometer,
Voltmeter,
Ammeter,



An electric current is always thought of as flowing from a higher to a lower level. We mark the higher level +, and the lower −, in order to denote in what direction the current is flowing. Sometimes **arrowheads are** also put on the wire. The current always flows from the + to the −. A given point is then + to all points below its level, and − to all points above its level. In Fig. 2 the long line of the battery cell represents the plus terminal and the short heavy line, the negative terminal. The current thus flows from *A* to *C* along the upper line.

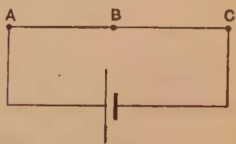


FIG. 2. Diagram of circuit connected to battery cell.

If then we are considering points *A* and *B*, the point *A* would be + and the point *B* −. But if we are considering *B* and *C*, *B* would then be + and *C* −.

Or in Fig. 3 consider the terminals *A* and *B*, across which an electric pressure is maintained. Since *A* is

marked +, it means that the current will flow from *A* and around to *B*, along whatever piece of electric apparatus is connected between the two points.

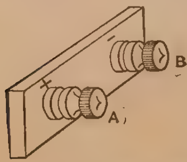


FIG. 3. Terminals of an electric circuit.

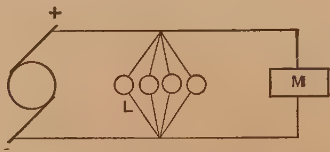


FIG. 4. Diagram of generator delivering power to lamps and motor.

The terminals on all D.C. instruments are marked in this way, in order to indicate that the + terminal is always to be connected to the higher level of the circuit.

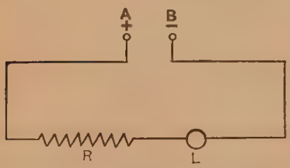


FIG. 5. Diagram of electric circuit.

Fig. 4 represents a d-c. generator lighting a bank of 4 incandescent lamps (*L*) and driving a motor (*M*). The current is flowing from the generator along the top of the circuit to the lamps and motor.

Sometimes merely the terminals of the source of the power are shown as *A* and *B*, in Fig. 5.

A = power terminal; R = resistance;
B = power terminal; L = incandescent lamp.

The current comes from *A*, goes through *R*, then *L*, and finally leaves at *B*.

6. Ohm's Law. Current. We have seen that if a certain current of electricity flows in a circuit, it flows because a certain pressure forces it to flow, and that the amount of the current is limited by the resistance of the circuit. If the pressure is one volt, and the resistance one

ohm, then one ampere current flows. If we wish to limit this current to $\frac{1}{4}$ ampere, then all we have to do is to make the resistance 4 times as much, or 4 ohms. That is, if the pressure is 1 volt and the resistance 4 ohms then only $\frac{1}{4}$ ampere flows. **Note that by dividing the pressure (1 volt) by the resistance (4 ohms), we obtain the current ($\frac{1}{4}$ ampere).**

Suppose, now, that the resistance of a circuit is 1 ohm and we wish to send 10 amperes through it. Since one volt will send 1 ampere through this 1-ohm resistance, to send 10 amperes through it would require 10 × 1 volt, or 10 volts.

That is, if the voltage is 10 volts and the resistance 1 ohm, then 10 amperes flow. **Note that the current 10 amperes may be found by dividing the pressure (10 volts) by the resistance (1 ohm).** Suppose, again, that in this circuit with the 10 volts pressure and 1-ohm resistance, we wish to limit the current to 5 amperes, instead of to 10 amperes. Since 10 volts can force just 10 amperes to flow through 1-ohm resistance, if we double the resistance, then 10 volts can force just one-half the current, or 5 amperes, through the circuit; that is, if the pressure is 10 volts and the resistance 2 ohms, then a current of 5 amperes flows.

Note again that the current (5 amperes) may be found by dividing the voltage (10 volts) by the resistance (2 ohms). In fact, the current which a given pressure will force through a given resistance can always be found by dividing the pressure (in volts) by the resistance (in ohms). This fact is usually stated as a great general law and is called Ohm's Law, after the man who first stated it.

OHM'S LAW

The current which an electric pressure forces through a resistance equals the pressure divided by the resistance.

This may be written briefly:

$$\textbf{Current} = \frac{\textbf{pressure}}{\textbf{resistance}},$$

or

$$\textbf{Amperes} = \frac{\textbf{volts}}{\textbf{ohms}}.$$

Example 1. How much current flows through an arc lamp which has 16 ohms resistance when a pressure of 80 volts is applied to it?

$$\begin{aligned}\text{Amperes} &= \frac{\text{volts}}{\text{ohms}}\\ &= \tfrac{80}{16} = 5 \text{ amperes.}\end{aligned}$$

Example 2. An incandescent lamp has a hot resistance of 400 ohms. It is placed across a 110-volt circuit. How much current flows?

$$\begin{aligned}\text{Amperes} &= \frac{\text{volts}}{\text{ohms}}\\ &= \tfrac{110}{400} = 0.275 \text{ ampere.}\end{aligned}$$

Problem 1. What current can 10 volts force through 5 ohms?

Problem 2. What current is produced by 40 volts acting across 0.25 ohm?

Problem 3. A dynamo generates 800 volts; the resistance of the circuit is 20 ohms. What is the current?

Problem 4. A dry cell has a terminal voltage of 1.2 volt when a wire of 0.2 ohm resistance is placed across its terminals. What current flows in the wire?

Problem 5. A dry cell has a terminal voltage of 0.90 volt, when a wire of 0.06 ohm resistance is across its terminals. What current is flowing through the wire?

Problem 6. Suppose a 2-ohm wire were placed across the cell of Problem 4 and the voltage remained the same. What current would flow through the wire?

Problem 7. The resistance of the coils in an electric bell is 140 ohms. What current flows when a pressure of 6 volts is put across the coils?

Problem 8. The resistance of a tungsten lamp when cold is 20 ohms. It is placed on a circuit of 115 volts. What current flows through the lamp the instant the switch is snapped on?

Problem 9. When the filament of a tungsten lamp is heated to a white heat, the resistance rises to 400 ohms. What steady current flows through the lamp in Problem 8, when it is glowing?

Problem 10. An electric car heater has about 100 ohms resistance. What current flows when the heater is placed across a trolley system of 550 volts?

Problem 11. If R = 11 ohms, Fig. 6, how many amperes are flowing in line?

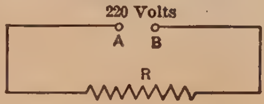


FIG. 6.

7. Measurement of Current. Ammeter. If we wish to measure the current of water which is flowing through a pipe, we insert a **flowmeter** into the pipe as (A) in Fig. 7. The current of water flowing through the pipe also flows through the flowmeter and causes it to indicate the number of gallons per second which pass through it. We can't attach an instrument to the outside of the pipe and find the current through the inside. We must open up the pipe and insert the instrument into the line so that the current which we wish to measure tends to flow directly through the instrument. Fig. 7a shows a water flowmeter of modern type. Note that the terminals are **inserted** into the pipe, so that the current of water tends to flow through the meter.

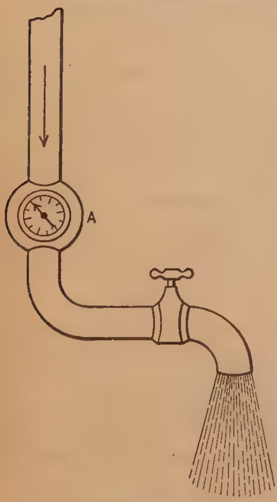


FIG. 7. Flowmeter A measures the gallons per sec. of water flowing through the pipe.

In the same way, if we wish to measure the current of electricity which is flowing through an electric circuit we insert a current meter into the circuit, so that all the current which we wish to measure flows through the meter. Since an instrument which measures an electric current must read in amperes, such a current meter is called an **ammeter** (a contraction of the term ampere-meter). Fig. 8 represents an ammeter (A) inserted in a line to measure the current flowing through the incandescent lamp (L). Note that all the current which goes through the lamp must pass through the ammeter. The ammeter then must be of very low resistance in order not to hinder the current. Such an instrument is very delicate and must be handled carefully. A fuller description showing the principles upon which it operates is to be found in Chapter VI. Sufficient practice in the use of this instrument should be gained by the student before proceeding further with the work.

FIG. 7a. General Electric flowmeter.

Note that the terminals of the ammeter are connected so that the current enters the meter at the plus (+) and leaves it at the negative (−) terminal.

8. Ohm's Law. Voltage. It may be desired at times to find the voltage required to force a certain current through a certain resistance. We have seen that it requires 10 volts to force 10 amperes through 1 ohm. Now, if we wished to force the 10 amperes through 2 ohms it would require 2 × 10 volts, or 20 volts. **Note that the voltage required is the product of the current (10 amperes) times the resistance (2 ohms).**

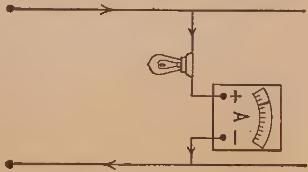


FIG. 8. The ammeter *A* measures the current flowing through the lamp.

Now suppose that we wish to force 5 times as much current, 50 amperes, through the 2 ohms. It would require just 100 volts or 5 times as much voltage. Note again that the pressure (100 volts) is the product of the current (50 amperes) times the resistance (2 ohms). This fact may be stated as a general law as follows:

The pressure required to force a given current through a given resistance is the product of the current times the resistance.

$$\textbf{Pressure} = \textbf{current} \times \textbf{resistance},$$

or

$$\textbf{Volts} = \textbf{amperes} \times \textbf{ohms}.$$

Example 3. The hot resistance of an incandescent carbon lamp is 220 ohms. It requires $\frac{1}{2}$ ampere to cause it to glow. What voltage must be impressed across it?

Voltage = amperes × ohms.
Voltage = $\frac{1}{2} \times 220 = 110$ volts.

Example 4. To ring a certain electric bell requires $\frac{1}{4}$ ampere. The resistance of the coils in the bell is 12 ohms. What voltage is required?

Voltage = amperes × ohms.
Voltage = $\frac{1}{4} \times 12 = 3$ volts.

Problem 12. What voltage will produce a current of 14 amperes through a resistance of 14 ohms?

Problem 13. What pressure is needed for an incandescent lamp of 40 ohms resistance, through which flows a current of 1.24 ampere?

Problem 14. What pressure will produce a current of 0.08 ampere through a resistance of 1000 ohms?

FIG. 9. Generator supplying lamp with current.

Problem 15. An electric bell has a resistance of 800 ohms and will not ring with a current of less than 0.02 ampere. What is the smallest pressure that will ring the bell?

Problem 16. In Fig. 9 lamp L has a resistance of 60 ohms. What voltage is needed across AC to force 2 amperes through the lamp?

Problem 17. The resistance of a telephone receiver is 90 ohms. The current required is 0.008 ampere. What voltage must be impressed across the receiver?

Problem 18. A miniature incandescent lamp requires 0.4 ampere to make it glow. The resistance is 8 ohms. What pressure is required?

Problem 19. What pressure is required to force 2000 amperes through 0.042 ohm?

9. Measurement of Pressure. Voltmeter. When we wish to measure the water pressure in a pipe, we tap a pressure gauge on to the pipe line, as (A) in Fig. 10. Note that no current flows through the gauge. It is merely **tapped on** to the pipe at the point at which we wish to measure the pressure, so that the pressure can get at it and cause it to indicate. The pipe, and current flowing through it, **are not** disturbed. Similarly, when we wish to measure the electric pressure causing an electric current to flow through, say a lamp, we do not disturb the circuit nor the current flowing through it. We just **tap** the terminals

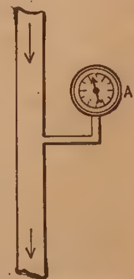


FIG. 10. The pressure gauge A indicates the pressure of the water in the pipe.

of a **voltmeter** on to the line, as in Fig. 11. We want to measure the pressure forcing the current through the lamp, so we tap the voltmeter leads on the terminals of the lamp. Note that the current which flows through the lamp does not go through the voltmeter. The voltmeter is not made to register current but pressure, and there is no need for the current to go through it, but it must be placed so that the pressure across the lamp is also across the voltmeter, the (+) side of the voltmeter being connected to the (+) side of the lamp. This pressure causes it to indicate the volts and not the current. Note that the method of connecting a voltmeter is quite different from the method of connecting an ammeter. An ammeter is **inserted into** the circuit, and becomes a part of the circuit, and receives the full current of the circuit. A voltmeter is **merely tapped on** to the circuit, and does not become a part of the circuit, nor does it receive the current which is flowing through the circuit. Great care must be used **not** to **tap on** an ammeter by mistake. An ammeter **tapped on** to a line in place of voltmeter is instantly ruined by the great rush of current.

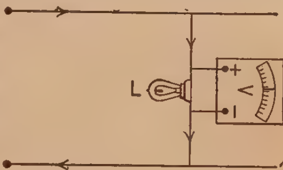


FIG. 11. The voltmeter *V* measures the pressure across the lamp.

10. Ohm's Law. Resistance. At times we wish to limit the current in a piece of apparatus to a certain number of amperes. If the pressure is known, it then becomes necessary to compute the resistance which will allow just this desired amount of current to flow, when the pressure is applied. We have seen that when the pressure is 10 volts and the resistance is 1 ohm, a current of 10 amperes flows. If we wish to limit the current to $\frac{1}{2}$ of 10 or 5 amperes, we must double the resistance and use 2 ohms.

That is, 10 volts can force just 5 amperes through 2 ohms. Note that the resistance (2 ohms) equals the pressure (10 volts) divided by the current (5 amperes). If the pressure had been 20 volts we should have had to use a resistance of 4 ohms to keep the current down to 5 amperes. Note again that the resistance necessary (4 ohms) is equal to the pressure (20 volts) divided by the current (5 amperes). The general law for this fact is stated as follows:

The resistance through which a given pressure will force a given current equals the quotient of the pressure divided by the current.

$$\textbf{Resistance} = \frac{\textbf{pressure}}{\textbf{current}},$$

or

$$\textbf{Ohms} = \frac{\textbf{volts}}{\textbf{amperes}}.$$

Example 5. What resistance must an electric heater have, if it is to be used on 550 volts and is to take 4 amperes?

$$\text{Resistance} = \frac{\text{pressure}}{\text{current}}.$$

$$\text{Resistance} = \tfrac{550}{4} = 137.5 \text{ ohms.}$$

Example 6. An arc lamp which takes a current of 6 amperes is to be used on a 110-volt circuit. What resistance must it have?

$$\text{Resistance} = \frac{\text{pressure}}{\text{current}}.$$

$$\text{Resistance} = \tfrac{110}{6} = 18.3 \text{ ohms.}$$

Problem 20. An incandescent lamp uses 0.5 ampere on a 110-volt circuit. What is the resistance of the lamp when burning?

Problem 21. Through what resistance will 121 volts force 11 amperes?

Problem 22. An electric soldering iron takes 1.2 ampere when used on a 110-volt circuit. What is the resistance of the iron?

Problem 23. Through what resistance will 15 volts force a current of 3 amperes?

Problem 24. What resistance must the 220-volt incandescent lamp in Fig. 12 have in order to take $\frac{1}{4}$ ampere?

Problem 25. The voltage across a certain piece of apparatus is found to be 14.8 volts. The current is found to be 21.5 amperes. What is the resistance?

Problem 26. What resistance must the coils of a bell be in order to limit the current to 0.04 ampere? The voltage across the coils is 6 volts.

FIG. 12.

11. Measurement of Resistance. Voltmeter and Ammeter Method. It can be seen from the above discussion that when we wish to find the resistance of an electrical piece, we have merely to measure the current which a known voltage can force through it, and divide the voltage by the current.

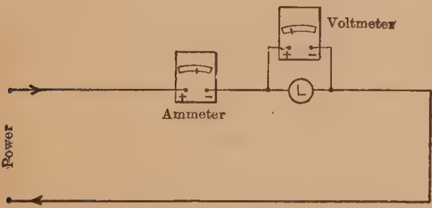


FIG. 13. "Ammeter and Voltmeter" method of measuring resistance of lamp.

Thus to find the resistance of the lamp (L), in Fig. 13, an ammeter is inserted in the circuit with it, and a voltmeter is tapped on around it. The voltmeter reading is divided by the ammeter reading and the result is the resistance of the lamp (L). This is the simplest method of obtaining the resistance of any electrical appliance when it is in use on a circuit.

12. Ohm's Law in its Three Forms. Ohm's Law states the relation which exists between the three electric quantities, Current, Pressure and Resistance. By means of this law we can find any one of the three quantities, if we know the other two. Thus, we use the law in three forms as follows:

To find the **Current**:

$$(1)\quad \textbf{Amperes} = \frac{\textbf{volts}}{\textbf{ohms}}.$$

To find the **Pressure**:

$$(2)\quad \textbf{Volts} = \textbf{amperes} \times \textbf{ohms}.$$

To find the **Resistance**:

$$(3)\quad \textbf{Ohms} = \frac{\textbf{volts}}{\textbf{amperes}}.$$

Example of (1). How many amperes flow in a circuit, when the pressure is 220 volts and the resistance is 40 ohms?

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}.$$

$$\tfrac{220}{40} = 5.5 \text{ amperes.}$$

Example of (2). How many volts are needed to force 4 amperes through 50 ohms?

$$\text{Volts} = \text{amperes} \times \text{ohms}.$$

$$= 4 \times 50 = 200 \text{ volts.}$$

Example of (3). Through how many ohms can 12 volts force 2 amperes?

$$\text{Ohms} = \frac{\text{volts}}{\text{amperes}}$$

$$= \tfrac{12}{2} = 6 \text{ ohms.}$$

SUMMARY OF CHAPTER I

ELECTRICITY may be considered to flow as a current along a conductor, very much as water flows through a pipe.

THE CURRENT of electricity is measured in AMPERES, which state the QUANTITY passing through conductor IN ONE SECOND.

THE PRESSURE which causes the current to flow is measured in VOLTS. Corresponds to "pounds per square inch."

THE RESISTANCE which a conductor offers to the current is measured in OHMS. Corresponds to the FRICTION in a pipe.

When two points of an electric circuit are marked, one (+) and the other (−), it always indicates that the current is considered to flow along the conductor from the (+) to the (−).

OHM'S LAW states the relation which exists among current, pressure and resistance. It is written in THREE forms.

1. $\text{Amperes} = \dfrac{\text{volts}}{\text{ohms}}$, that is, $\text{Current} = \dfrac{\text{pressure}}{\text{resistance}}$.

2. $\text{Volts} = \text{amperes} \times \text{ohms}$,
   that is, $\text{Pressure} = \text{current} \times \text{resistance}$.

3. $\text{Ohms} = \dfrac{\text{volts}}{\text{amperes}}$, that is, $\text{Resistance} = \dfrac{\text{pressure}}{\text{current}}$.

CURRENT is measured by INSERTING a low resistance ammeter INTO the line.

VOLTAGE is measured by TAPPING a high resistance voltmeter ACROSS two points in the line.

RESISTANCE is measured by dividing the VOLTMETER reading by the AMMETER reading according to Ohm's law.

CAUTION. Be careful not to tap an ammeter on to a circuit as you would a voltmeter. Always BREAK the circuit and INSERT the ammeter.

PROBLEMS ON CHAPTER I

Problem 27. If a car heater is supplied with a pressure of 550 volts from the trolley line, how great must its resistance be that the current may not exceed 6 amperes?

Problem 28. A dynamo generates a pressure of 1450 volts and delivers a current of 40 amperes. What is the resistance of the circuit?

Problem 29. What voltage must a generator produce to supply an electroplating current of 25 amperes through a circuit whose total resistance is 0.2 ohm?

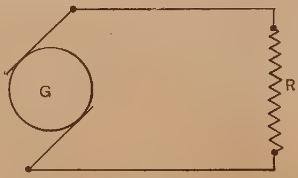


Fig. 14.

Problem 30. The generator G in Fig. 14 has a voltage of 220 volts. What current can it force through R which is 12.3 ohms?

Problem 31. What voltage must the generator in Problem 30 deliver in order to force 42 amperes through R?

Problem 32. If the resistance of an electric bell is 65 ohms and it requires 0.2 of an ampere to ring it, will a battery of 10 volts be sufficient?

Problem 33. A carbon filament lamp made to burn on a 220-volt circuit has a resistance of 420 ohms. What current does it take?

Problem 34. What current would the lamp of Problem 33 take, if by mistake it were placed on a 110-volt line? Assume that the resistance of the lamp remains the same.

Problem 35. In order to take the same current that the lamp in Problem 34 takes, what resistance must a carbon incandescent lamp have which runs on a 110-volt circuit?

Problem 36. An ammeter made to measure 5 amperes, has a resistance of 0.009 ohms. How much current will flow through the ammeter if by mistake it is used as a voltmeter across 110 volts?

Problem 37. A voltmeter made to measure 150 volts has a resistance of 15,000 ohms. How much current flows through it when it is placed across a 110-volt line?

Problem 38. In Fig. 15 the voltmeter (*V*) indicates 112 volts, and the ammeter (*A*), 4.1 amperes. What is the resistance of the lamp (*L*)?

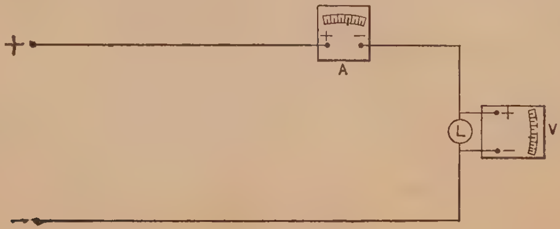


FIG. 15.

Problem 39. What voltage is required to force 2000 amperes through 0.0083 ohm?

Problem 40. The field coils of a shunt motor have a resistance of 418 ohms. How much current flows through them when the pressure across them is 220 volts?

Problem 41. The arc lamp, Fig. 16, has a hot resistance of 216 ohms. The voltmeter (*V*) reads 112 volts. How much will the ammeter (*A*) read?

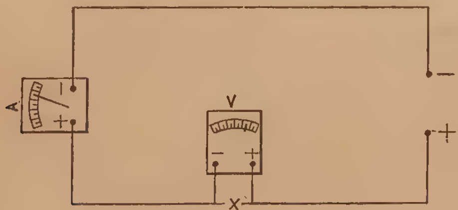


FIG. 16.

Problem 42. Which resistance is the greater; one which requires 12 volts to force a current of 5.19 amperes through it, or one which requires 550 volts to force 261 amperes through it?

Problem 43. A cable has a resistance of 0.481 ohm and a current of 40.2 amperes flows through it. What is the voltage required to force this current through the cable?

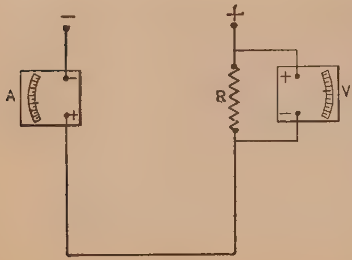


FIG. 17.

Problem 44. What current would flow in the cable of Problem 43 if the pressure forcing the current through it became 22.8 volts?

Problem 45. The voltage across the terminals of a generator is 115 volts and 12.7 amperes are flowing. What is the resistance of the circuit?

Problem 46. In Fig. 17 the resistance of R is 19.2 ohms. The ammeter (A) reads 4.13 amperes. What should the voltmeter (V) read?

Problem 47. A 220-volt lamp has a resistance of 438 ohms. A 110-volt lamp has a resistance of 225 ohms. Which takes the larger current when burning on its proper voltage?

Problem 48. If the lamps in Problem 47 were put on each other's circuit, how much current would each take? Assume resistance to remain unchanged.

Problem 49. The resistance of a telegraph line is 3240 ohms. If 75 volts are used on the line what current flows?

Problem 50. An arc lamp has a resistance of 13 ohms and requires a current of 6 amperes. How much resistance must be added to it, if it is to carry just 6 amperes when burning on a 110-volt line?

Problem 51. A short circuit is made, by accidentally placing a wire of 0.0001 ohm resistance across 110 volts. What was the current in the short-circuiting wire?

CHAPTER II

SIMPLE ELECTRIC CIRCUITS

13. Series Circuits and Parallel Circuits Defined. There are two ways of connecting two or more pieces of electrical apparatus.

(1) **Series.** When the pieces are connected in **tandem,** or

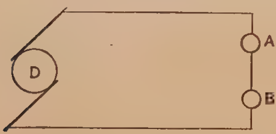


FIG. 18. A and B are in series.

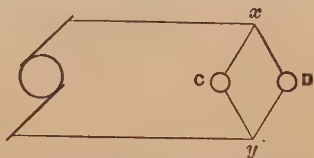


FIG. 19. Parallel combination; *C* is in parallel with *D*.

one after the other, they are said to be in **series.** Lamps *A* and *B* of Fig. 18 are in series.

(2) **Parallel.** When the pieces are connected side by side so that the current is divided between them, they are said

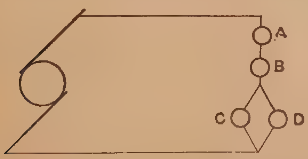


FIG. 20. Series arrangement of parallel and series combinations.

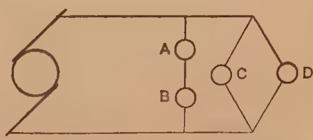


FIG. 21. Parallel arrangement of series and parallel combinations.

to be in **parallel** with one another. **Multiple** or **shunt** are other names for this same combination. Lamps *C* and *D* of Fig. 19 are in parallel with each other.

The two combinations may exist in the same circuit, as

in Fig. 20, where the parallel combination *C* and *D* is in series with the series combination *A* and *B*.

Also, as in Fig. 21, where the parallel combination *C* and *D* is in parallel with the series combination *A* and *B*.

In this chapter only simple series and simple parallel circuits will be considered.

14. Series Circuit. Current. If we join four pipes *A*, *B*, *C* and *D*, Fig. 22, of unequal diameters together in series, and force a current of water through them, the water cannot go in at *M* in any greater quantity per second than it comes out at *N*. There must be the same current (gallons per second) flowing through each pipe no matter what its size, because no more or less can go through one than goes through all the others.

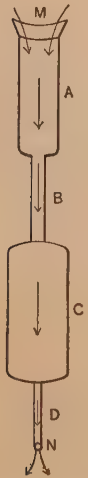


FIG. 22. Series arrangement of pipes; same current in each.

Similarly, we may join together in series several electrical pieces, as in Fig. 23, a resistance coil (*R*) of 10 ohms, an electric bell (*B*) of 50 ohms, and an incandescent lamp (*L*) of 200 ohms. Although the resistance of the coil *R* is much lower than that of the bell or the lamp, still no greater current can flow through the coil than can get through the bell and lamp. No more electric current can enter at one end of an electric circuit than can get out at the other end, any more than can a greater current of water enter at one end of a pipe line than can go out at the other.

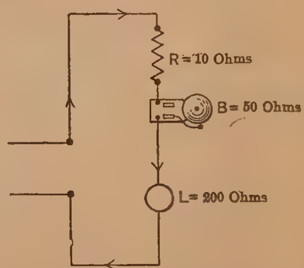


FIG. 23. Series arrangement of lamp, bell and coil. The same current flows through each.

The first fact then to be noted is that:

In a series circuit the current is the same in all parts, no matter what the resistance may be.

15. Series Circuit. Resistance. In Fig. 24, a resistance coil R of 10 ohms is connected across the terminals of a 110-volt line. By Ohm's Law the current must equal $\frac{\text{volts}}{\text{ohms}} = \frac{110}{10} = 11$ amperes.

Now suppose a lamp (L) having 45 ohms resistance is joined in series with the coil (R) across the same circuit of

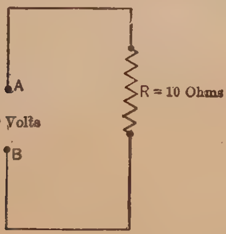


FIG. 24. A coil of 10 ohms across a 110-volt circuit.

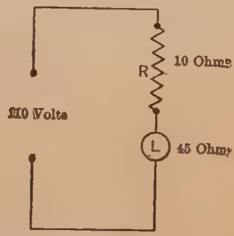


FIG. 25. Lamp and coil in series across a 110-volt circuit.

110 volts as in Fig. 25. It is plain that the lamp and coil now offer a greater resistance to the current than did the coil alone. In fact, the resistance of the two pieces joined in this way is just the sum of their separate resistances, that is, 10 + 45, or 55 ohms.

The current that flows can now be found by Ohm's Law.

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}} = \frac{110}{55} = 2 \text{ amperes.}$$

The flow of water is similarly checked by the addition of more lengths of pipe in series.

The second fact to be noted about a series circuit is that:

The combined resistance of pieces in series is the sum of the separate resistances.

Example. (*a*) What is the resistance of the circuit in Fig. 26? (*b*) What current flows in this circuit?

$$\text{Resistance} = 200 + 200 + 40 = 440 \text{ ohms.}$$

$$\text{Current} = \frac{\text{volts}}{\text{ohms}} = \frac{220}{440} = 0.5 \text{ ampere.}$$

Problem 1. (*a*) What is the total resistance of the circuit connected across the terminals of the generator in Fig. 27?

(*b*) What current flows in the circuit if the generator maintains a pressure of 125 volts?

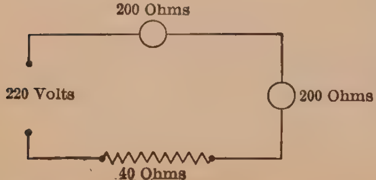


FIG. 26. The two lamps and coil are in series across a 220-volt line.

Problem 2. (*a*) If 6 lamps of 13 ohms each are inserted in the line in Problem 1, what will the total resistance be?

(*b*) What will the voltage have to be in order to force 3 times the current of Prob. 1 through each lamp?

Problem 3. What resistance must each lamp have in Fig. 28 in order to allow a current of 16 amperes to flow in each?

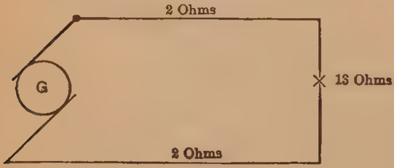


FIG. 27. An arc lamp in series with line wires across a generator.

FIG. 28. Three arc lamps in series across a generator.

16. Series Circuit. Voltage. Suppose a coil (R) of 5 ohms resistance, and an arc lamp (A) of 17 ohms resistance are joined in series, as in Fig. 29, across a 110-volt line.

We have seen that the total resistance is 5 + 17 = 22 ohms. The current flowing through the circuit is found as usual by Ohm's Law.

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}} = \frac{110}{22} = 5 \text{ amperes.}$$

Since this is a series circuit, the same current flows in each part of it. Thus there are 5 amperes flowing through the coil (R), and 5 amperes flowing through the arc lamp (A).

We are able also by Ohm's Law to find the voltage required to force the 5 amperes through the coil of 5 ohms, since volts = amperes × ohms. Thus, for the coil,

$$\begin{aligned} \text{volts} &= \text{amperes} \times \text{ohms} \\ &= 5 \times 5 = 25 \text{ volts.} \end{aligned}$$

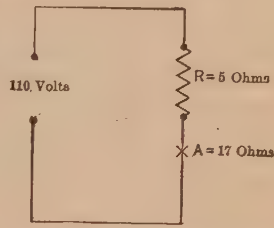


FIG. 29. A coil and arc lamp in series across a 110 volt line.

There are required, then, 25 volts to force the 5 amperes through the 5-ohm coil.

In the same way we may find the voltage required to force the 5 amperes through the 17-ohm arc lamp. Because for the arc lamp Ohm's Law is still true, so

$$\begin{aligned} \text{volts} &= \text{amperes} \times \text{ohms} \\ &= 5 \times 17 = 85 \text{ volts.} \end{aligned}$$

There are required then 85 volts to force the current of 5 amperes through the arc lamp. We found that 25 volts are required to force the current through the 5-ohm coil.

To force the current through both, it requires 110 volts, which fact is shown by their being on a 110-volt line.

Note that the 110 volts required to force the current through the two pieces exactly equals the sum of the 25 volts across the coil R and the 85 volts across the lamp; that is, $25 + 85 = 110$ volts. It is always true in a series circuit, that if we add up the voltages across all the pieces in series, the sum will exactly equal the voltage across the series combination.

The third fact, then, to be noted about a series circuit is that:

> **The voltage across the pieces in series equals the sum of the voltages across the separate pieces.**

17. Series Circuit. Current, Resistance and Voltage. The three facts which should be learned with regard to a series circuit may be tabulated as follows:

Series Combination

Current through series combination is	same as current through each separate part.
Resistance of series combination is	the sum of the resistances of the separate parts.
Voltage across series combination is	the sum of voltages across the separate parts.

Example 2. In the series circuit of Fig. 30, 3 amperes are flowing.
(*a*) What is the voltage across AB?
(*b*) What is the voltage across each piece?

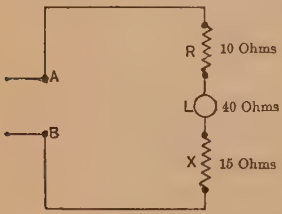


Fig. 30. Series combination.

(*a*) The total resistance $= 10 + 40 + 15 = 65$ ohms.
Voltage to force 3 amp. through 65 ohms $= 3 \times 65 = 195$ volts.
Answer to (*a*) then is: Voltage across AB is 195 volts.

(*b*) Volts to force 3 amp. through R (10 ohms) $= 3 \times 10 = 30$ volts.
" " " 3 " " L (40 ohms) $= 3 \times 40 = 120$ "
" " " 3 " " X (15 ohms) $= 3 \times 15 = 45$ "
Volts to force 3 amp. through $R+L+X$ (65 ohms) $= 195$ volts.

This answer checks with the volts found in part (*a*) to be necessary to force 3 amperes through the series combination.

Problem 4. (*a*) If each lamp, Fig. 31, of the combination takes 1.5 ampere, how many amperes must the generator deliver?

(*b*) Resistance of $A = 300$ ohms;
" " $B = 200$ "
" " $C = 150$ "
Combined resistance = ?

Problem 5. There are seven arc lamps in series, Fig. 32, each requiring 8 amperes. If each has a resistance of 13 ohms, how many volts must the dynamo supply to the system?

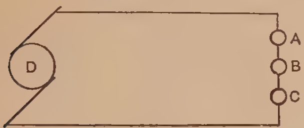


FIG. 31.


FIG. 32.

Problem 6. Motor *M* requires 20 amperes at 220 volts, in Fig. 33. The line wires have a resistance of 0.25 ohm each. What pressure must be supplied by the generator?

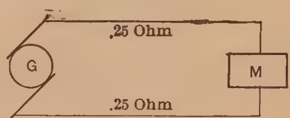


FIG. 33.

18. Application of Ohm's Law. It should be noted that in solving the Example on page 28, Fig. 30, Ohm's Law was used in (*a*) to find the voltage necessary to force the current through the whole circuit of the three resistances, *R*, *L* and *X*.

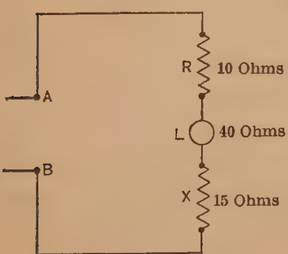


FIG. 34.

First, the total resistance was found by adding $10 + 40 + 15 = 65$ ohms.

Then, to find the total voltage necessary, we said:

(Total) voltage = (total) current $\times$ (total) resistance.

(Total) voltage $= 3 \times 65 = 195$ volts.

Note that to find the **total** voltage, it was necessary to use the **total** current and **total** resistance.

But later when we wished to find the voltage necessary to force the current through the 10-ohm coil **only**, we used Ohm's Law again. But this time, since we wanted the voltage across the 10-ohm coil **only**, we used the resistance of the 10 ohms **only**, and not the total resistance of the circuit. We also had to use the current through the 10-ohm coil **only**. **Thus we said:**

Voltage (across 10-ohm coil) = current (through 10-ohm coil) × resistance (of 10-ohm coil) = 3 × 10 = 30.

Thus to find the voltage across the 10-ohm coil, we used the current through the 10-ohm coil and the resistance of the 10-ohm coil.

Thus it can be seen that Ohm's Law may be applied either to the whole of a circuit or to any part of a circuit.

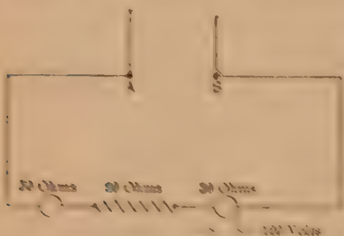


Fig. 35. Two lamps and a coil in series.

But if it is applied to the whole circuit, the voltage, resistance and current must be the voltage, resistance and current of the whole circuit, and not of merely a part. And if it is applied to a part of a circuit, the voltage, current and resistance must be the voltage, current and resistance of **just that part,** and no more or less.

This is of vital importance in applying Ohm's Law. Many mistakes are made in the use of this simple law, just because we fail to be careful to use the voltage, current and resistance of the **same** part of the circuit.

Note the use of this rule in the following:

Example 8. In Fig. 35 a lamp of 50 ohms, a resistance of 20 ohms, and another lamp of 30 ohms are connected in series across

the points A and B. The 30-ohm lamp has a pressure of 120 volts across it.

Find:

(*a*) Current through each piece.
(*b*) Voltage across each piece.
(*c*) Voltage across AB.

We are able to find the current through the 30-ohm lamp, because we know **both** the resistance and pressure.

$$\text{Current (through 30-ohm lamp)} = \frac{\text{voltage (across 30-ohm lamp)}}{\text{resistance (of 30-ohm lamp)}}$$
$$= \tfrac{120}{30} = 4 \text{ amp.}$$

Thus the current through the 30-ohm lamp is 4 amperes. But since the 50-ohm lamp and the 20-ohm resistance are in series with the 30-ohm lamp, the same current must pass through them. Therefore, we can find the voltage across the 20-ohm coil as follows:

$$\begin{aligned}\text{Voltage (across 20-ohm coil)} &= \text{current (through 20-ohm coil)} \\ &\quad \times \text{resistance (of 20-ohm coil)} \\ &= 4 \times 20 = 80 \text{ volts.} \\ \text{Voltage (across 50-ohm lamp)} &= \text{current (through 50-ohm lamp)} \\ &\quad \times \text{resistance (of 50-ohm lamp)} \\ &= 4 \times 50 = 200 \text{ volts.}\end{aligned}$$

Since this is a series circuit, the voltage across the whole circuit, that is, across AB, equals the sum of the voltages across the separate parts, or

$$\text{voltage across } AB = 120 + 80 + 200 = 400 \text{ volts.}$$

The answers then are

(*a*) Current through each part = 4 amperes.
(*b*) Voltage across 20-ohm coil = 80 volts.
" " 50-ohm lamp = 200 volts.
(*c*) Voltage across AB = 400 volts.

Note that after we had found the current of the **whole** circuit, we might have added up the resistances and found the resistance **of** the **whole** circuit, thus $30 + 20 + 50 = 100$ ohms.

Then voltage (across total circuit) = current (through total circuit) × resistance (of total circuit).

$$4 \times 100 = 400 \text{ volts.}$$

This checks with the total voltage as found by the first method.

Problem 7. Lamp *L*, Fig. 36, requires 0.2 ampere. Voltage of the generator is 220 volts:

(*a*) How many volts are used to send current through the line wires?

(*b*) What voltage is there across the lamp?

(*c*) What is the resistance of the lamp?

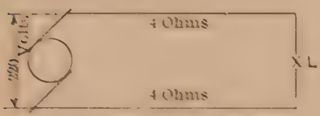


Fig. 36.

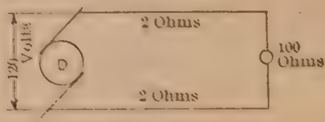


Fig. 37.

Problem 8. The lamp in Fig. 37 has a resistance of 100 ohms, and the line wires 2 ohms each.

(*a*) What is the current in the line?

(*b*) What is the voltage across the lamp?

(*c*) How much voltage is used up in sending the current through the line wires?

Problem 9. A 10-ohm resistance is joined in series with a 25-ohm resistance.

(*a*) What is the resistance of the combination?

(*b*) How much voltage across the combination is required to force 12 amperes through the resistances?

Problem 10. What will be the voltage across each resistance in Problem 9?

Problem 11. Six arc lamps are joined in series. Each has a resistance of 14 ohms. If the line wires have a total resistance of 7 ohms, how much voltage is required to send 6 amp. current through the lamps and line?

Problem 12. (*a*) What is the voltage across each lamp in Problem 11? (*b*) What voltage is used to send the current through the line?

Problem 13. The motor in Fig. 38 requires 13.2 amp. at 112 volts. What must be the voltage across the generator?

Problem 14. What voltage is required to send 9 amp. through a series of resistances consisting of 12 ohms, 14 ohms and 22 ohms?

Problem 15. What resistance must be inserted in series with two resistances of 20 ohms and 30 ohms respectively, which are connected in series, in order that 112 volts may force but 1.24 amp. through the whole combination?

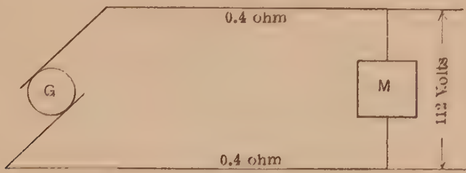


Fig. 38.

Problem 16. Ammeter (A), Fig. 39, reads 2.4 amp.; voltmeter (V) reads 41 volts.

Find:

(a) Resistance of R.
(b) Voltage across 36 ohms.
(c) Voltage across 42 ohms.
(d) Voltage across generator.

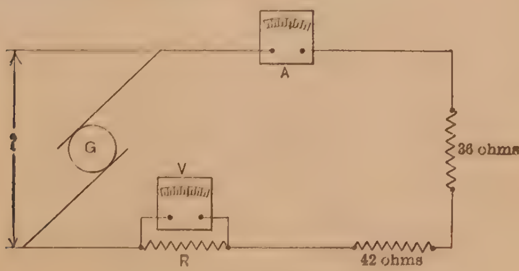


Fig. 39.

19. Parallel Circuit. Voltage. Suppose, as in Fig. 40, we should join two main pipes R and S by means of three parallel pipes A, B and C. All the parallel pipes lie between the same two levels, that is, the levels of R and S. Thus there is the same difference of level across them. We have seen that it is this difference of level that causes the

pressure, and tends to cause a current to flow from the higher level to the lower. In this case, the water flowing through *A*, *B* and *C* enters all pipes at the same high level

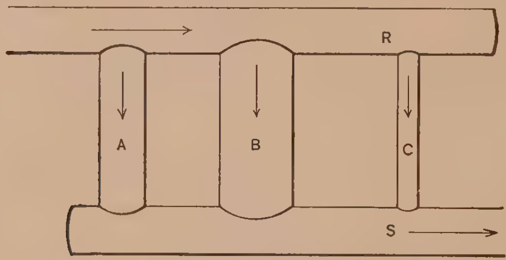


FIG. 40. The pipes *A*, *B* and *C* are in parallel.

and leaves at the same low level. Since the water is forced to flow by the pressure caused by the same difference in level, it may be seen that the pressure across each pipe is the same. In each case it is merely the pressure between *R* and *S*. If we put a thousand pipes between *R* and *S*, the pressure across them would be the pressure beween *R* and *S* and, therefore, the pressure across them would be the same.

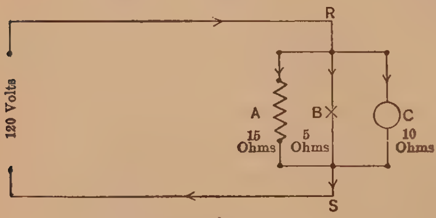


FIG. 41. The coil *A*, arc lamp *B* and incandescent lamp *C*.

Similarly, suppose we join three electrical pieces *A*, *B*, *C*, Fig. 41, in parallel, between two main wires *R* and *S*. They all lie between *R* and *S*, and whatever voltage there is across *RS* will be across each of the pieces *A*, *B* and *C*. The voltage across each will, therefore, be the same, that is, the voltage across *RS*, or 120 volts. Thus the voltage

across A is 120 volts, the voltage across B is 120 volts and the voltage across C is 120 volts.

The first thing to be noted in a parallel circuit is that:

> **The voltage across the parallel combination is the same as the voltage across each branch.**

20. Parallel Circuit. Current. Turning again to Fig. 40, it is seen that, since the pipes A, B and C are not joined in series, they are independent of one another, and do not have to carry the same current. In fact, it is very evident that the largest pipe will carry the largest current and the smallest pipe the smallest current. Water and electricity **do not** take the path of least resistance. They take **all** paths. Where the path is of small resistance, a heavy current flows. Where there is a path of large resistance, a small current flows. But the water or the electricity is sure to make use of **both** the low resistance and the high resistance paths and force as much current as possible through both. The total current that flows through is merely the sum of the currents in the separate paths.

Thus, in Fig. 41, since the resistance of the branch A is high, a small current only will flow through it. By applying Ohm's Law to this branch alone, we can find this current. We have seen that the voltage across A is 120 volts. Now the resistance is 15 ohms and Ohm's Law applies as follows to find the current:

$$\text{Current (through } A) = \frac{\text{voltage (across } A)}{\text{resistance (of } A)}$$
$$= \tfrac{120}{15} = 8 \text{ amp.}$$

Similarly, we can find the current through B.

$$\text{Current (through } B) = \frac{\text{voltage (across } B)}{\text{resistance (of } B)}$$
$$= \tfrac{120}{5} = 24 \text{ amp.,}$$

and also the

$$\text{current (through } C) = \frac{\text{voltage (across } C)}{\text{resistance (of } C)}$$
$$= \tfrac{120}{10} = 12 \text{ amp.}$$

The current then flowing between R and S by all three paths is merely the sum of these currents or $8 + 24 + 12 = 44$ amp. This is also the current in the two main wires.

The second fact to notice in a parallel circuit is that:

> **The current flowing through the parallel combination is merely the sum of the currents in the separate branches or paths.**

Problem 17. Through M, Fig. 42, 4 amperes flow. Through M', 12 amperes. Total amperes in line equal what?

Problem 18. Each lamp in Fig. 43 takes 0.24 amp. How much current flows in the main line?

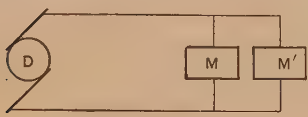


FIG. 42.

21. Parallel Circuit. Resistance. Suppose that it is desired to find the resistance of a parallel combination, as A, B and C, in Fig. 44. There are many formulas for this, but the easiest method is to apply Ohm's Law as follows:

We have seen that

The current through $A = \tfrac{120}{15} = 8$ amperes.
The " " $B = \tfrac{120}{5} = 24$ "
The " " $C = \tfrac{120}{10} = 12$ "
Current through combination $= 44$ amperes.

Now since we know the **current through the combination** (44 amp.) and the **voltage across the combination** (120 volts) we can find the **resistance of the combination.**

$$\textbf{Resistance} \text{ (of combination)} = \frac{\text{voltage (across combination)}}{\text{current (through combination)}}$$
$$= \tfrac{120}{44} = 2.73 \text{ ohms.}$$

At first sight it may seem strange that the resistance of a combination of three pieces of 5, 10 and 15 ohms should be only 2.73 ohms. But the apparent difficulty disappears when we consider that the more paths we have in parallel for the current to flow from one point to another, the lower the resistance between those two points. Thus, if there had been only the 5-ohm path between the points *R* and *S*, then the resistance between these points would have been 5 ohms. But when another path of 10 ohms was run between the same points *R* and *S*, more current could flow and thus the resistance between the points became less than 5 ohms. And when a third resistance of 15 ohms was added, the resistance became still smaller. Thus we may see that the resistance of any parallel combination is less than the resistance of the path of smallest resistance. The path having the smallest resistance in this case is the 5-ohm path, and the combined resistance of the three parallel paths amounts to but 2.73 ohms.

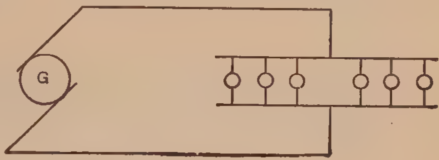


FIG. 43.

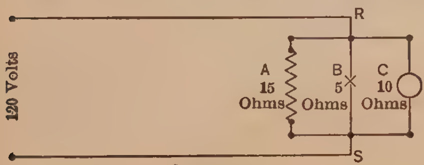


FIG. 44.

Or, referring to Fig. 40, it can be seen that the more pipes there are connected in parallel between the main pipes *R* and *S*, the easier it is for the water to get from one main pipe to the other. Hence the smaller the resistance between the main pipes.

Suppose we were given merely the three parallel resistances *A*, *B* and *C*, Fig. 44a, and there were no mention

made of any voltage across them. We could find the resistance of the parallel combination as follows:

First find the current that one volt would force through each branch.

Current (per volt) through $A = \frac{1}{15} = 0.0667$ amp.
Current " " " $B = \frac{1}{5} = 0.2$ "
Current " " " $C = \frac{1}{10} = 0.1$ "
Current through combination = sum = $\overline{0.3667}$ amp.

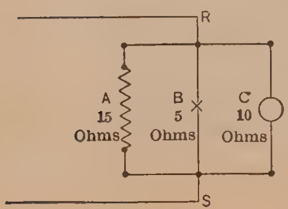


FIG. 44a.

Now if one volt would force 0.3667 amp. through the combination,

$$\text{Resistance (of combination)} = \frac{\text{voltage (across combination)}}{\text{current (through combination)}}$$

$$= \frac{1}{0.3667} = 2.73 \text{ ohms.}$$

This checks with the value found above.

We have used the expression " Current per volt " in the above paragraph, as for instance,

current per volt through $A = \frac{1}{15}$ amp.
and current per volt through $B = \frac{1}{5}$ amp.

Note that this value, $\frac{1}{15}$, is the reciprocal (or inverse) of the resistance of A (15 ohms), and the value $\frac{1}{5}$ is the reciprocal of 5, the resistance of B (5 ohms). This reciprocal of the resistance is sometimes called the **conductance.** Thus, in the last example, a piece of

15 ohms resistance has $\frac{1}{15}$ **conductance.**
5 " " has $\frac{1}{5}$ "
10 " " has $\frac{1}{10}$ "

Note that the larger the resistance is, the smaller the conductance becomes. The conductance of a parallel combination is merely the sum of the conductances of the separate branches. Thus 0.3667 is the conductance of the parallel combination in the example.

Conductance, then, is merely another name for the term "Amperes per volt," or "Current per volt."

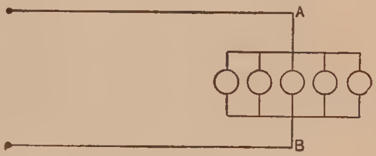


FIG. 44b.

When the several branches of a parallel combination are of the same resistance, the problem becomes very easy.

Suppose that in Fig. 44b the resistance of each lamp is 200 ohms. Since there are five equal paths for the current to flow through, it must be 5 times as easy to get from *A* to *B* by 5 paths as by one path. That is, the resistance of the 5 parallel paths must be only $\frac{1}{5}$ as great as the resistance of one path. Thus the resistance of the parallel combination simply equals $\frac{200}{5} = 40$ ohms.

If we had been given that the resistance of the combination was 40 ohms, and were required to find the resistance of each, it would seem rather strange to multiply the resistance of the combination (40 ohms) by 5 in order to get the resistance of one path. But this would be the correct method because the resistance of but one path must be 5 times as much as the resistance of 5 parallel paths.

The third fact to note about a parallel combination is that:

The resistance of a parallel combination is found by applying Ohm's Law. First find the current through each branch. Add these to find the current through the combination. Then the resistance of the combination equals the voltage across the combination divided by this current through the combination. When no voltage across the combination is given, use one volt.

Example 4. Resistances of 2 ohms, 3 ohms and 4 ohms are joined in parallel. What is the resistance of the combination?

Current (per volt) through 2 ohms	$= \frac{1}{2}$	$= 0.5$	amp.
" " " " 3 ohms	$= \frac{1}{3}$	$= 0.333$	"
" " " " 4 ohms	$= \frac{1}{4}$	$= 0.25$	"
" " " " combination	= sum	$= 1.083$	amp.

$$\text{Resistance (of combination)} = \frac{\text{voltage (across combination)}}{\text{current (through combination)}}$$

$$= \frac{1}{1.083} = 0.923 \text{ ohm.}$$

The three facts which should be known about a parallel combination may be tabulated as follows:

(Compare them with the Series Table in Summary.)

Parallel Combination

Current through parallel combination equals	sum of currents through separate branches.
Voltage across parallel combination is	same as voltage across each branch.
Resistance of a parallel combination is	less than resistance of the branch having smallest resistance and can be found by Ohm's Law plus a little common sense.

PROBLEMS ON PARALLEL COMBINATIONS

Problem 19. A parallel circuit has resistances in the several branches of 2, 4, 5 and 10 ohms, respectively. What is the conductance of the combination? What is the resistance?

Problem 20. (*a*) If a pressure of 50 volts is impressed across the combination in Problem 19, what current will flow in each branch? (*b*) What will be the total current through the combination?

Problem 21. What pressure is required to force 9 amperes through a parallel combination consisting of a 4-ohm branch, a 10-ohm branch and a 12-ohm branch?

Problem 22. A circuit consists of three parallel branches of 1 ohm, 2 ohms and 3 ohms, respectively. What is the resistance of the combination?

Problem 23. The sum of the currents in the 2-ohm and 3-ohm branches of a circuit, such as that of Problem 22, is 7 amperes.

(a) What voltage is there across the terminals of the combination?

(b) What current is flowing through the 1-ohm branch?

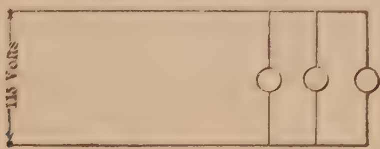


FIG. 45.

Problem 24. The three lamps of Fig. 45 have the same resistance. The sum of the currents taken by the 3 lamps when on the 115-volt circuit is 1.5 amp. What is the resistance of each lamp?

SUMMARY OF CHAPTER II

Electrical pieces connected in TANDEM are said to be in SERIES.

Electrical pieces connected SIDE BY SIDE are said to be in PARALLEL.

Series Combination

Current through series combination is	same as current through separate parts.
Resistance of series combination is	sum of resistances across the separate parts.
Voltage across series combination is	sum of voltages across separate parts.

Parallel Combination

Voltage across parallel combination is	same as voltage across each branch.
Current through parallel combination is	sum of currents through each branch.
Resistance of parallel combination is	less than resistance of branch of smallest resistance. It is found by using Ohm's Law plus a little common sense.

Ohm's Law applied to any electric circuit should read:

The amperes through any PART of a circuit equal the volts through that same PART of the circuit, divided by the ohms of that same PART of the circuit.

PROBLEMS ON CHAPTER II

Problem 25. If the magneto-generator for ringing a telephone bell gives a pressure of 50 volts, what current will be transmitted through the circuit? The resistance of the line is 10 ohms and of the bell is 325 ohms.

Problem 26. What pressure will be required to force 2 amperes through a series circuit containing line wires of $2\frac{1}{2}$ ohms, and a lamp of 100 ohms resistance?

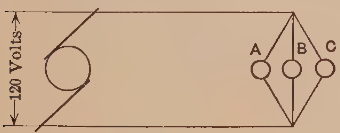


FIG. 46.

FIG. 47.

Problem 27. In Fig. 46 (parallel combination):

Resistance A = 60 ohms;
" B = 40 "
" C = 90 "
Voltage across combination = 120 volts.

Find:

(*a*) Voltage across each.
(*b*) Current through each.
(*c*) Current through combination.
(*d*) Resistance of combination.

Problem 28. If each lamp of the combination, Fig. 47, takes 1.5 ampere, how many amperes must the generator deliver?

Problem 29. A divided circuit has two branches of 1 ohm and $\frac{1}{4}$ ohm, respectively. What is the joint conductance of the two branches? What is the joint resistance?

Problem 30. A circuit has three branches of 12, 4 and 16 ohms, respectively. If 4 amperes flow in the circuit containing 16 ohms, what current will flow in each of the others?

Problem 31. If 12 lamps of 226 ohms each are put in parallel across 110 volts, find:

(*a*) Resistance of the combination.
(*b*) Current through each lamp.
(*c*) Current through the combination.

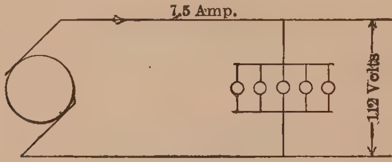


FIG. 48.

Problem 32. In Fig. 48, 7.5 amp. flow in the line, and the lamps have 112 volts across them.

Find:

(*a*) Current through each lamp.
(*b*) Resistance of each lamp.
(*c*) Voltage across each lamp.
(*d*) Resistance of the combination.

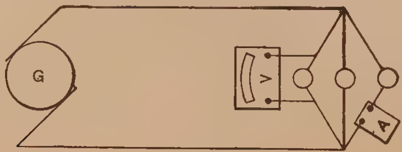


FIG. 49.

Problem 33. In Fig. 49, the three lamps have practically the same resistance. Voltmeter (*V*) reads 113 volts. Ammeter (*A*) reads 0.45 amp.

Find:

(*a*) Resistance of each lamp.
(*b*) Current in the main line.
(*c*) Voltage across each lamp.

Problem 34. In Fig. 50, the ammeter reads 5.4 amp. Each lamp has a voltage of 100 volts across it.

Find:
(*a*) Voltage across *R*.
(*b*) Resistance of *R*.
(*c*) Resistance of each lamp.

Problem 35. If one lamp in Problem 34, Fig. 50, becomes short-circuited, what will *R* have to be made to keep the current down to 5.4 amp.?

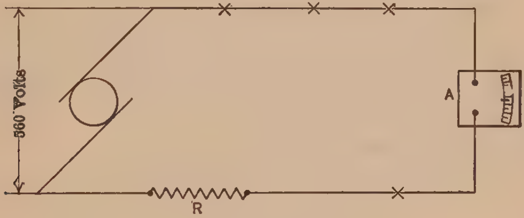


Fig. 50.

Problem 36. If one lamp in Problem 32 becomes open-circuited, what voltage must be put across the remaining four lamps in order that the current in the line may remain the same? Consider the resistance of each lamp to remain as in Problem 32.

Problem 37. Three resistances, one of 12 ohms, one of 17 ohms and a third unknown are placed in parallel. The resistance of the combination is 3.89 ohms. What is the third resistance?

Problem 38. If the 17-ohm resistance of Problem 37 is carrying 2.4 amp., how much current is each of the other two resistances carrying?

Problem 39. What pressure will be required to force 12 amperes through a parallel combination consisting of 4 ohms, 15 ohms and 8 ohms?

Problem 40. Three pieces, one of 16 ohms, one of 22 ohms, and a third of 28 ohms are placed in series across a 110-volt line. It is found that a current of 1.55 amp. flows. What must be the resistance of the wires used to connect the pieces?

Problem 41. What is the voltage across each piece in Problem 40?

Problem 42. In Fig. 51, the arc lamp has a resistance of 18 ohms, the incandescent lamp has a resistance of 84 ohms and a current of 1.32 amp. The line carries a current of 9 amp.

Find:

(*a*) Voltage across the parallel combination.
(*b*) Current through the resistance (R).
(*c*) Resistance of (R).
(*d*) Resistance of the combination.

Problem 43. A telegraph line works on 10 volts. What current is sent through it, if the resistance of the line wire is 500 ohms?

Problem 44. If a relay of 100 ohms resistance were inserted in series with the line wire of Problem 43, what current would 10 volts send through the line?

FIG. 51.

Problem 45. What voltage would there be across the relay of Problem 44?

Problem 46. The voltage between the trolley wire and the rails of an electric railway is 550 volts. In order to make a single 110-volt, 0.5 amp. carbon lamp burn on this circuit, how much resistance must be placed in series with it?

Problem 47. What voltage is required across a line on which there are 12 arc lamps in series, each of 8 ohms resistance, if each lamp requires 6 amp. to operate it? Count the line wire resistance as 10 ohms.

Problem 48. How many arc lamps each having a resistance of 7 ohms and requiring a current of 6.5 amp. can be run in series on a 1200-volt line? Neglect the resistance of the line wire.

Problem 49. If the line wire in Problem 48 has a resistance of 12 ohms, how many arc lamps could be run in series on it as per Problem 48?

Problem 50. The terminals of a generator have a pressure of 115 volts. What current will flow if a wire of 0.02 ohm be connected across the terminals?

Problem 51. What current will flow if an incandescent lamp of 400 ohms be connected across the generator of Problem 50?

Problem 52. The copper bus-bar on the back of a switchboard is carrying 500 amperes. The voltage across the ends of it is found to be 0.4 volt. What is the resistance of the bus-bar?

Problem 53. The arc lamp in Fig. 52 requires 6 amp. at 85 volts across the arc to make it burn with a steady light. What resistance R must be added to the lamp in order to run it on a 115-volt line?

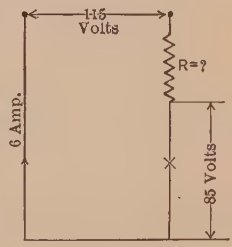


FIG. 52.

Problem 54. The resistance of an arc lamp is 12.3 ohms. It requires 6.5 amp. to make it burn properly. How much resistance must be added to enable it to be run on a 115-volt line?

Problem 55. The resistance of a parallel circuit of two branches is 4 ohms. The resistance of one of the branches is 20 ohms. What is the resistance of the other?

Problem 56. If 6 amperes are sent through the 20-ohm branch of Problem 55:

(a) What voltage will be required?

(b) What current will flow in the other branch?

Problem 57. The average resistance of the human body is 10,000 ohms. About 0.1 ampere through the body is usually fatal. What is the lowest voltage which would ordinarily kill a person?

Problem 58. It requires 4.8 volts to force a current of 40 amperes through 5 miles of wire. What is the resistance of the wire per mile?

Problem 59. What voltage would be required to force 60 amp. through 8 miles of the wire in Problem 58?

Problem 60. How much resistance must be placed in series with a coil on a 110-volt line in order to reduce the current from 2.18 amp. to 1.84 amp.?

Problem 61. (*a*) What is the voltage across *AD*, Fig. 53?
(*b*) What is the voltage across *AB*?

Problem 62. What voltage would be required to send 8 amp. through the line in Problem 61?

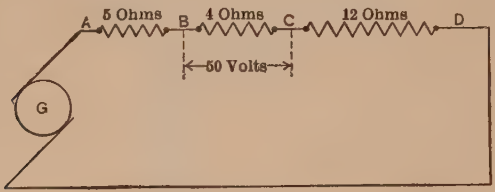


FIG. 53.

Problem 63. What would be the combined resistance of the wires in Fig. 53, if they were joined in parallel?

Problem 64. What voltage would be required to send 8 amperes through the resistances joined as in Problem 63?

Problem 65. What would be the current through each resistance in Problem 64?

CHAPTER III

COMBINATIONS OF SERIES AND PARALLEL SYSTEMS

22. Parallel Lighting Systems. Modern incandescent lamps are usually installed in parallel. The resistance of all the lamps, even of the same make, is not the same. Nor is the voltage across all the lamps when installed the same. Still, for convenience in calculating the " line drop in voltage," that is, the voltage necessary to send current through the line, each lamp is assumed to take the same current. The error introduced by this assumption is usually too small to be taken into account.

In practice, it is seldom that we find a simple series circuit, or a simple parallel circuit. The two arrangements are usually combined into a more or less complicated system. But by considering each part of the circuit by itself and applying Ohm's Law to each part separately, it is easy to find the current, voltage and resistance distribution throughout the entire circuit of any system. The same rules that we have learned, apply, and apply in the same way. A little practice is all that is needed in order to solve the most difficult of such arrangements.

For instance, consider the following:

Example 1. In a lighting system, as shown in Fig. 54, each lamp takes $\frac{1}{2}$ amp. at 110 volts. We wish to find the voltage which the generator must deliver in order to force the current through the line wires and still have 110 volts left to force the current through the lamps.

The parallel combination of four lamps BC is really in series with the two line wires AB and CD.

First, we find the current distribution throughout the whole circuit and mark it upon the diagram as in Fig. 55.

We start with the parallel combination of lamps. As the lamps are in parallel, the current through the combination BC must be the sum of the currents through each branch. Thus the current from B to C must be 4×0.5 amp. or 2 amp.

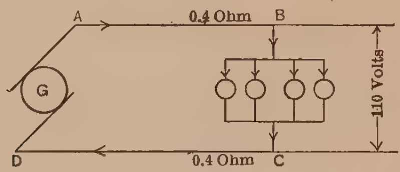


FIG. 54.

Now, since the line wire AB is in series with the combination BC, the same current must flow through the line wire AB as flows through the parallel combination BC. Thus the 2 amperes must flow through the line wire AB.

The line wire CD is also in series with the parallel combination BC, so the same current (2 amperes) must flow through CD.

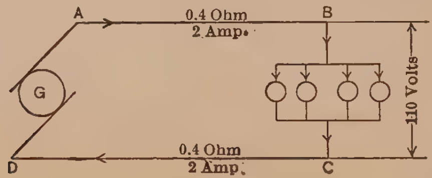


FIG. 55.

We now have the current distribution throughout the entire circuit. We can then find the voltage distribution in the same way. First find the voltage necessary to force the current through the line. We must force 2 amperes through a line wire AB, of 0.4 ohm resistance in order to get it to flow through the lamps.

To force 2 amperes through 0.4 ohm requires $0.4 \times 2 = 0.8$ volt. (Volts = ohms $\times$ amperes.) Thus it requires 0.8 volt to get the current out to the lamps.

Similarly, it requires 0.8 volt to get the current back from the lamps to the generator through the line wire CD, since we must

force the same 2 amperes through the 0.4-ohm resistance of this wire. The voltage is then distributed as in Fig. 56.

Thus we have the voltages across the three parts of the circuit which are in series. The voltage across the whole series system then, is the sum of the voltages across the separate parts.

Voltage across	*AB*	=	0.8 volt
" "	lamp	=	110.0 "
" "	*CD*	=	0.8 "
" "	combination	=	111.6 volts.

The 1.6 volts used to send the current through the line wires is said to be the "volts lost in the line," or "line drop."

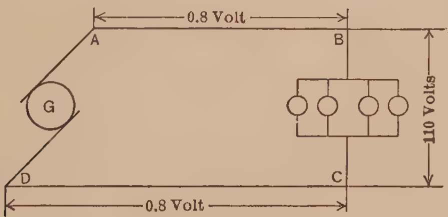


Fig. 56.

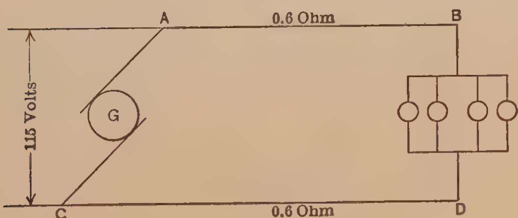


Fig. 57.

Therefore the generator must impress 111.6 volts on the system in order to use 0.8 volt forcing the current through the section of line out to the lamps, and 0.8 volt forcing it through the return section, and still have 110 volts left for the lamps.

The general method of attack for this type of problem may then be summarized as follows:

First. Find the current distribution throughout the circuit.
Second. Find the voltage distribution throughout the circuit.
Third. Combine the voltages according to the rules for a series circuit.

Prob. 1. The generator in Fig. 57 delivers a pressure of 115 volts.
(a) If each lamp takes 1 ampere, what will be the voltage across the lamps?
(b) What will be the line drop?

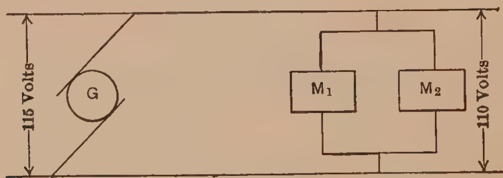


FIG. 58.

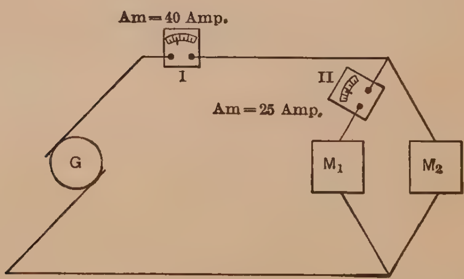


FIG. 59.

Prob. 2. In Fig. 58, M_1 takes 10 amp., M_2 takes 15 amp. How much resistance can each line wire have in order that the voltage of the generator may be 115 volts, and 110 volts may be supplied at the motors?

Prob. 3. In Fig. 59, ammeter I reads 40 amperes; ammeter II reads 25 amp. How much current does M_2 take?

Prob. 4. In Fig. 60, bell 1 requires 0.2 amp. to operate it, bell 2 requires 0.4 amp., bell 3 requires 0.8 amp. When all three bells are ringing at the same time, what current flows from the cells?

Prob. 5. The line wires of Problem 4 have 1.5 ohm total resistance. What voltage is used up in the line wires when bells 1 and 3 are rung at the same instant?

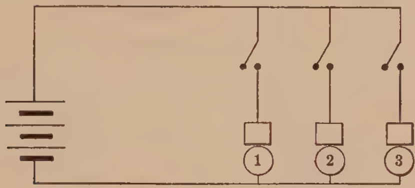


FIG. 60.

23. More Complicated Grouping. In the above examples, it will be noted that all parts of the line wires carry the same current. Systems are usually arranged so that the several sections of the line wires carry different currents, the section nearest the generator carrying more than the sections further away.

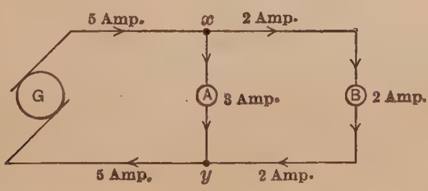


FIG. 61.

Suppose, as in Fig. 61, two lamps A and B are connected to a circuit in such a way that A, taking 3 amperes, is much nearer the generator than B, which takes 2 amperes. Then in the section of the line which lies between A and B, 2 amperes must flow in order to supply lamp B with

2 amperes. But the section of the line between the generator and A must carry enough current to supply both lamp A and lamp B. Thus this section must carry 5 amperes as in Fig. 61. When this current of 5 amperes in the line reaches the point (x) it divides, 3 amperes going down through the lamp A and the rest (2 amp.) going on

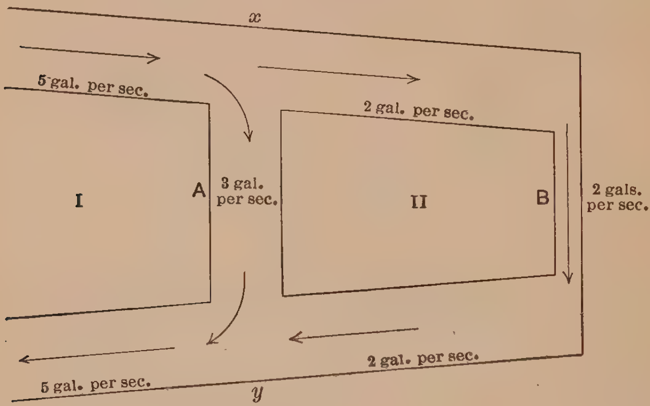


FIG. 62.

through the other section to supply the lamp B. Similarly, at the point (y) the two currents join, the 3 amperes coming from lamp A joining the 2 coming along the further section of the line from lamp B, and their combined current of 5 amperes is carried by the section of line wire between A and the generator.

The above electrical circuit is similar to the water pipe circuit of Fig. 62. The two pipes A, carrying 3 gal. per sec. and B, carrying 2 gal. per sec. Section I of the pipe line must carry 5 gal. per sec. in order to supply both pipes A and B. Section II, supplying B only, has to carry but 2 gal. per sec. At point (x) the current of 5 gal. per sec.

divides, and 3 gal. per sec. flow through A and 2 gal. per sec. go on through Section II to supply pipe B. At (y) the 2 gal. per sec. from Section II join the 3 gal. per sec. from pipe A, and together they pour a current of 5 gal. per sec. through the lower pipe of Section I.

In Fig. 63, the sections AB and DE of the line are nearest the generator and thus have to carry enough current to supply both groups of lamps. Since Group I takes 4 amperes and Group II takes 3 amperes the generator must supply 7 amperes, and sections AB and DE of the line must carry 7 amperes.

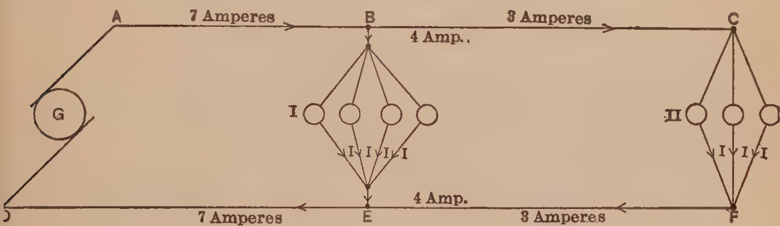


FIG. 63.

Sections BC and EF, however, feed Group II only, and thus carry only enough current to supply these lamps, namely 3 amperes.

It is very often convenient to regard the current distribution as follows:

Begin with the lamps farthest from generator. Group II requires 3 amp., therefore, sections BC and EF must carry 3 amperes.

Group I requires 4 amperes. The part of the line AB, therefore, must bring enough current to the point B, so that 3 amperes can be sent out along BC to Group II and 4 amperes can be sent down through Group I to the point E. Thus AB must carry $4 + 3$, or 7 amperes.

Similarly, at E, the 4 amperes from Group I and the 3 amperes from EF pour into the line DE and thus DE also must carry 7 amperes.

Prob. 6. If each lamp, Fig. 64, takes 0.4 ampere, how much current flows in the following sections of the line: AB, BC, DE and EF?

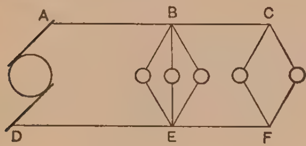


FIG. 64.

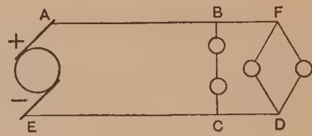


FIG. 65.

FIG. 66.

Prob. 7. In Fig. 65, each lamp takes 2 amperes. How much current flows through AB, BF, EC and CD?

Prob. 8. In Fig. 66:

Car 1 takes 50 amperes.
" 2 " 60 "
" 3 " 40 "

How much current flows in the trolley wire between:

(a) Cars 2 and 3?
(b) Cars 1 and 2?
(c) Generator and car 1?

24. Voltage Required for the Line. Line Drop. Let us assume that a circuit, Fig. 67, is arranged as in Fig. 61, except that the resistance of the line wires and the generator voltage are introduced. The wires from the generator G to the lamp A each have a resistance of 0.3 ohm. The wires from the lamp A to the lamp B each have a resistance of 0.4 ohm.

First Step. Current Distribution. As we saw in Fig. 61 each of the wires from G to A has a current of 5 amp. flowing through it, and each of the wires from A to B has a current of 2 amp.

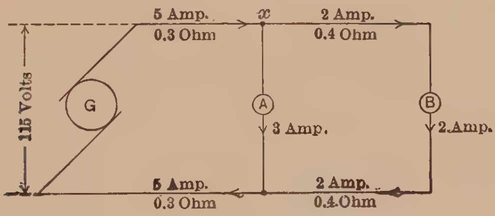


FIG. 67.

Second Step. Voltage Required for the Line. Line Drop. We have seen that it requires a voltage to force a current through a wire. Thus, to force the current of 5 amp. out from the generator along a 0.3-ohm wire to the point (x) would require

$$5 \times 0.3, \text{ or } 1.5 \text{ volts (volts = amperes} \times \text{ohms).}$$

And to force a current of 5 amp. back from y to the generator through a 0.3-ohm line wire requires

$$5 \times 0.3, \text{ or } 1.5 \text{ volts.}$$

Thus, just to force the current along the section of the line out to the lamp A and back again requires 1.5 + 1.5, or 3 volts.

Third Step. Voltage across the Lamps. If we assume that the generator furnishes a voltage of 115 volts, and that 3 volts are used in forcing the current through the first section of the line, then all that remains for the lamp A is

$$115 - 3, \text{ or } 112 \text{ volts.}$$

A voltmeter placed across the generator would read 115

volts, but a voltmeter placed across lamp (A) would read only 112 volts. The 3 volts used in forcing the current through the line are said to be lost in the line, and are called the "line drop."

In the same way, to force the 2 amperes through the 0.4-ohm line out to lamp (B) requires 2×0.4, or 0.8 volt. And to force this 2-amp. current back from lamp (B) to point (y) through the 0.4-ohm line wire requires 2×0.4, or 0.8 volt. So to force the current from (x) to lamp (B) and back again to (y) requires $0.8 + 0.8$, or 1.6 volts.

Since we have only 112 volts across (x) and (y) (that is, across lamp A), if we use 1.6 volts just to force the current out to lamp B and back again, we have left but

$$112 - 1.6, \quad \text{or} \quad 110.4 \text{ volts},$$

to force the current through lamp B.

If we should put a voltmeter across lamp B, then, it would read only 110.4 volts.

Another way of looking at this problem is to draw a diagram somewhat as in Fig. 68. This shows very clearly that there are two paths between the points (x) and (y). One path is directly through the lamp (A). The other is through the 0.4-ohm line wires and lamp (B). Therefore, the lamp (A) is in parallel with the series combination of lamp (B) and the 0.4-ohm line wires, since both are connected across the points (x) and (y). So after we have found that the voltage across (x) and (y) is $115 - 3$, or 112 volts, then we know that the voltage across each of the two parallel circuits is the same.

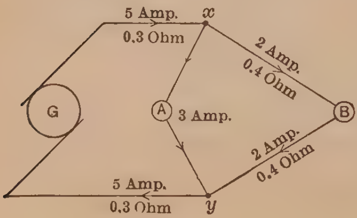


FIG. 68.

Therefore, the voltage across lamp *A* is 112 volts, and the voltage across the series combination of the two 0.4-ohm wires and lamp *B* is 112 volts.

But we have seen that it required 1.6 volt to force the current through the two 0.4-ohm wires. Since there were 112 volts across the series combination of lamp *B* and line wires, if it requires 1.6 volt for line wires alone, there are left for lamp (*B*), 112 − 1.6, or 110.4 volts.

25. Generator Voltage. It is sometimes required to find what the voltage across the generator must be, in order to produce a given voltage across a set of lamps at a distance from the generator. This is merely a variation of the preceding example and is solved by the same method, as may be seen from the following.

Figs. 63 and 69 are identical except that in Fig. 69 the resistance of the line wire is known and the voltage across Group II is given as 110 volts. It is required to find the voltage across the generator and Group I.

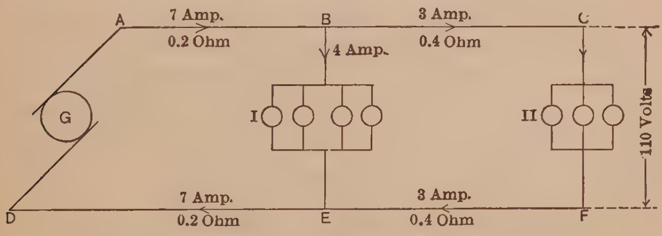


FIG. 69.

First Step. Current Distribution. Note that as each lamp takes 1 amp., the current distribution in Fig. 69 is the same as in Fig. 63. That is, between Groups I and II, the line carries 3 amp. Between the generator and Group I, the line carries 7 amp. It is also essential to note that in all problems of this type we have **started by finding the current distribution.**

Second Step. Line Drop. In the section between Groups I and II, the 0.4-ohm line wire BC carries 3 amp. It must require 3×0.4, or 1.2 volt to force this current through this wire. Similarly, it requires 3×0.4, or 1.2 volt to force the current through EF. Thus the "line drop" between Groups I and II must be $1.2 + 1.2 = 2.4$ volts.

Third Step. If there are 110 volts across Group II after the 2.4 volts have been lost in the line wires from Group I to Group II, there must be $110 + 2.4$, or 112.4 volts across Group I.

Or, stating it another way:

Line wire BC, Group II and line wire FE are in series. Therefore, the voltage across the combination, that is, B to E, must be the sum of the voltages across the separate parts.

Voltage across	BC =	1.2 volts.
" "	Group II =	110.0 "
" "	FE =	1.2 "
Voltage across BE (sum)	=	112.4 volts.

But since Group I of lamps is also across the points B and E, the voltage across Group I must also be 112.4 volts.

Similarly, the voltage used up in forcing 7 amp. through the 0.2 ohm of wire $AB = 7 \times 0.2 = 1.4$ volt. And the voltage used in forcing the 7 amp. through the 0.2 ohm of the wire $ED = 7 \times 0.2 = 1.4$ volt.

Voltage across generator AD = (voltage across AB) + (voltage across BE) + (voltage across ED).

Voltage across	AB =	1.4 volts.
" "	BE =	112.4 "
" "	ED =	1.4 "
Voltage across the Generator (AD)	=	115.2 volts.

Thus, the voltage across the	Generator =	115.2 volts
" " "	Group I =	112.4 "
" " "	Group II =	110.0 "

The method in all the above is the same.

First Step. Mark the current distribution on the diagram beginning at the section farthest from the generator.

Second Step. Compute the line drop in the different sections of the line by Ohm's Law.

Third Step. By means of the laws for series or for parallel circuits compute the voltage across the various groups, etc.

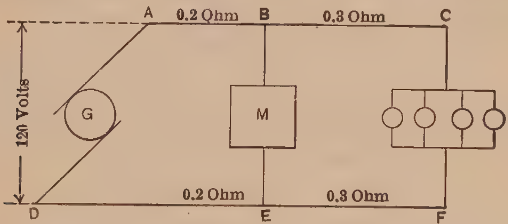


FIG. 70.

Prob. 9. Each lamp, Fig. 70, takes 2 amperes. Motor M takes 10 amp.

Find:

(*a*) Line drop in each section of the line.
(*b*) Voltage across lamps.
(*c*) Voltage across motor.

Prob. 10. What is the resistance of each lamp in Problem 9?

Prob. 11. In Fig. 64,

Resistance AB = Resistance DE = 1.5 ohms.
" BC = " EF = 2.0 "
Voltage across BE = 112 volts
Each lamp takes 1.4 amp.

Find:

(*a*) Line drop in each section of the line.
(*b*) Voltage across AD.
(*c*) Voltage across CF.

Prob. 12. Find the resistance of each lamp in Problem 11.

SUMMARY OF CHAPTER III

Combinations of series and parallel arrangements can be separated into small parts and Ohm's Law applied to each part, in order to find the current, voltage and resistance distribution.

METHOD. (First step.) Find the current distribution beginning at the point farthest from the generator.

(Second step.) Compute, by means of Ohm's Law, the line drop.

(Third step.) Combine line drop with known voltages, according to the rules for series and parallel circuits.

PROBLEMS ON CHAPTER III

Prob. 13. In Fig. 65 each lamp takes 2.5 amp.

Voltage of generator = 125 volts.
Resistance $AB = EC = 0.8$ ohm.
" $BF = CD = 0.7$ ohm.

Find:

(*a*) Current through each section of the line.
(*b*) Line drop in each section of the line.

Prob. 14. Find the voltage across CB and FD, in Problem 13.

Prob. 15. If the two lamps which are across BC in Problem 13 are of the same resistance, how great is the resistance of each?

Prob. 16. What is the resistance of each lamp across CF in Problem 13?

Prob. 17. Assume the voltage across the generator in Fig. 66 to be 550 volts.

Resistance of trolley between generator and car I	= 0.5	ohm.
" " " " car I " car II	= 1.2	"
" " " " car II " car III	= 0.4	"
Resistance of track between generator and car I	= 0.05	"
" " " " car I " car II	= 0.1	"
" " " " car II " car III	= 0.04	"

Other data as in Problem 8.

Find:

(a) Voltage drop in each section of the trolley wire.
(b) Voltage drop in each section of the track.
(c) Voltage across each car.

Prob. 18. Assume the voltage of the generator in Fig. 66 as unknown but that the voltage across car II is 550 volts. Other data as in Problem 17.

Find:

(a) Voltage drop in each section of the trolley wire.
(b) Voltage drop in each section of the track.
(c) Voltage across Generator and each car.

Prob. 19. In Fig. 71, each lamp takes 1.2 amp.

Find:

(a) The amount and direction of the current in the following sections of the line: *FT*, *ET*, *BC*, *AB*.
(b) The voltage drop in each of the above sections of line.

Prob. 20. Find the voltage across each lamp of Fig. 71, if the generator voltage is 125 volts, and each lamp takes 1.2 amp.

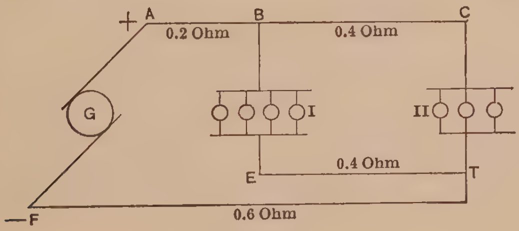


FIG. 71.

Prob. 21. Find the voltage across the generator and Group I in Fig. 71 if the voltage across Group II is 112 volts and each lamp takes 1.2 amp.

Prob. 22. Each lamp in Fig. 72 takes 1.5 amp. Voltage across the switch = 110 volts. Resistance of each section of wire between the lamps, and from the switch to the lamps, is 0.2 ohm.

Find:

(*a*) The amount and direction of the current flowing in each section of the wire.
(*b*) Voltage drop in each section of wire.
(*c*) Voltage across each lamp.

Prob. 23. If the wiring of Problem 22 were arranged as in Fig. 73, and all the data were the same as in Problem 22. Find:

(*a*) Amount and direction of the current in each section.
(*b*) Volts drop in each section.
(*c*) Voltage across each lamp.
(*d*) Which is the better method of making connections: this, or that of Problem 22?

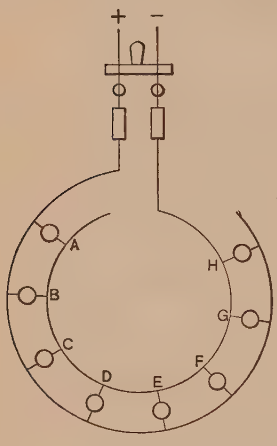


FIG. 72.

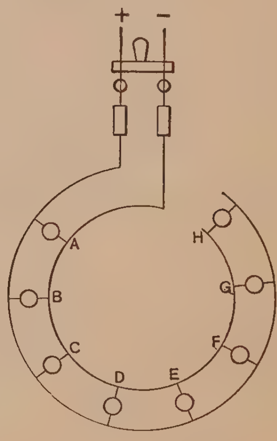


FIG. 73.

Prob. 24. In Fig. 74, each lamp takes 2 amp. The motor takes 10 amp. The voltage across the lamps must be 110 volts.

Find:

(*a*) The volts drop in the line between the lamps and motor.
(*b*) The voltage across the motor.
(*c*) The resistance of the line between the generator and lamps.
(*d*) The average resistance of the lamps.

Prob. 25. In Fig. 74, assume the resistance of the line wires from the generator to the lamps to be 0.16 ohm each, and the voltage across the lamps to be unknown. What will be the voltage across the motor when the lamps are not running?

Prob. 26. What will be the voltage across the lamps in Problem 25 when the motor is not running?

Prob. 27. What will be the voltage across the lamps when the motor in Problem 25 is running?

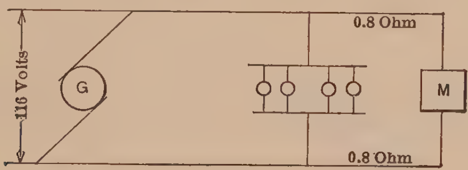


FIG. 74.

Prob. 28. What will be the voltage across the motor and lamps in Problem 25, if the motor and lamps interchange places on the line?

Prob. 29. The voltage at a generator station is 120 volts. When a load of 200 amperes flows, the voltage at the consumer's end of the line is 115 volts. What is the line resistance?

Prob. 30. On the consumer's end of the line in Problem 29, is a motor. When the motor is started alone on the line, the voltage at the motor drops to 112 volts. When the motor gets up speed, the voltage across it remains steady at 114 volts.

(*a*) What current does the motor take on starting?

(*b*) What current does the motor take when running?

CHAPTER IV

ELECTRIC POWER

26. Unit of Power. Watt. Incandescent lamps are rated as to the voltage of the line on which they can run, and also as to the amount of electric power it takes to keep them glowing. Thus, a carbon filament lamp may be rated as a 110-volt, 50-watt lamp. A tungsten lamp may be rated as a 110-volt, 25-watt lamp. This means that both lamps are intended to run on a 110-volt circuit, but that it takes twice as much power to keep the carbon filament lamp glowing as it does to keep the tungsten lamp glowing.

The flow of an electric current has been likened to the flow of water through a pipe. A current of water is measured by the number of gallons, or pounds, flowing per minute; a current of electricity, by the number of amperes, or coulombs per second. The power required to keep a current of water flowing is the product of the current in **pounds per minute** by the head, or pressure, in **feet.** This gives the power in **foot pounds per minute.** To reduce to horse power, it is necessary merely to divide by 33,000, i.e., $\frac{\text{(lb. per min.)} \times \text{(feet)}}{33{,}000} = \text{horse power.}$

In exactly the same way, the **power** required to keep a current of electricity flowing is the product of the current in **amperes** by the pressure in **volts.** This gives the power in **watts.**

$$\textbf{Watts} = \textbf{amperes} \times \textbf{volts.}$$

The term **watt** is merely a unit of power, and denotes the power used when one volt causes one ampere of current

to flow. The watts consumed when any given current flows under any pressure can always be found by multiplying the current in amperes by the pressure in volts. Thus, if an incandescent lamp takes 0.5 amp. when burning on a 110-volt line, the power consumed equals

$$0.5 \times 110 = 55 \text{ watts.}$$

That is,

$$\text{power} = \text{current} \times \text{pressure},$$

or

$$\text{watts} = \text{amperes} \times \text{volts.}$$

Example 1. What power is consumed by a motor which runs on a 220-volt circuit, if it takes 4 amperes?

$$\begin{aligned} \text{Watts} &= \text{amperes} \times \text{volts} \\ &= 4 \times 220. \\ \text{Power} &= 880 \text{ watts.} \end{aligned}$$

Prob. 1. A 20-candle-power tungsten lamp takes 0.227 amp. when on a 110-volt line. What is its rating in power consumed?

Prob. 2. How many watts are used in the lamp in Problem 1 to produce each candle power?

Prob. 3. An arc lamp takes 5 amp. at 110 volts. What power is consumed?

Prob. 4. How much power is taken by 5 incandescent lamps if each is rated as a 40-watt lamp?

Prob. 5. What would be the power rating of a 32-candle-power incandescent lamp, which used 3.5 watts per candle power?

27. Current taken by Lamps. Just as Ohm's Law is used in its three forms, so the power equation is also used in three forms.

If

$$\text{watts} = \text{amperes} \times \text{volts},$$

then

$$\text{amperes} = \frac{\text{watts}}{\text{volts}}.$$

Example 2. What current will a 25-watt lamp take when burning on a 110-volt line?

$$\text{Watts} = \text{amperes} \times \text{volts},$$

or
$$\text{amperes} = \frac{\text{watts}}{\text{volts}}$$
$$= \tfrac{25}{110} = 0.227 \text{ amp.}$$

Prob. 6. What current does a motor take which uses 440 watts on a 110-volt line?

Prob. 7. An arc lamp is rated at 100 watts on a 110-volt line. What current does it take?

Prob. 8. What current does a 20-candle-power tungsten lamp take on a 112-volt circuit, if it requires 1.25 watt per candle power?

28. Voltage Required by Lamps. The power equation appears in a third form. This form is used when it is desired to find the voltage which will produce a given amount of power using a given current.

For if
$$\text{watts} = \text{amperes} \times \text{volts},$$

then
$$\text{volts} = \frac{\text{watts}}{\text{amperes}}.$$

Example 3. On what voltage must a 40-watt lamp be used if it is to take a current of 0.357 amp.?

$$\text{Volts} = \frac{\text{watts}}{\text{amperes}}$$
$$= \frac{40}{0.357} = 112 \text{ volts.}$$

Prob. 9. A motor is rated to take 5 amp. and to consume 1200 watts. For what voltage is it built?

Prob. 10. If the motor of Problem 9 took 10 amp., but consumed the same power, for what voltage would it be built?

Prob. 11. A 50-candle-power lamp, rated as 1.5 watt per candle power, is to take 0.341 amp. On what voltage should it be run?

29. Three Forms of Power Equation. The power equation, then, has these three forms:

To find **power,**

$$(1) \qquad \textbf{watts} = \textbf{amperes} \times \textbf{volts.}$$

To find **current,**

$$(2) \qquad \textbf{amperes} = \frac{\textbf{watts}}{\textbf{volts}}.$$

To find **voltage,**

$$(3) \qquad \textbf{volts} = \frac{\textbf{watts}}{\textbf{amperes}}.$$

Prob. 12. How many watts are consumed by the electric iron in Fig. 74a which uses 2.3 amp. in a 110-volt circuit?

Prob. 13. How much power is consumed by the group of lamps in Fig. 54?

Prob. 14. If motor M_1, Fig. 59, consumes 2750 watts, what is the voltage across it?

Prob. 15. A trolley car has a voltage of 540 volts and uses 21,000 watts. What current does it take?

FIG. 74a. General Electric iron with heating unit removed.

Prob. 16. What current does a 60-watt, 115-volt tungsten lamp take if it uses 1.2 watt per candle-power?

30. Measurement of Power in an Electric Circuit. If we wish to know the power that is being consumed in a **certain part** of an electric circuit, we merely have to insert an ammeter to measure the current in **that part** of the circuit, apply a voltmeter to measure the voltage across **that part** of the circuit, and multiply the ammeter reading by the voltmeter reading. This gives us the power directly in watts. The computation is thus merely an application of the general method which we have already expressed in the equation:

$$\text{Watts} = \text{volts} \times \text{amperes}.$$

The same precautions must be observed in the use of this equation as in the use of Ohm's Law. That is, the voltage and the current must be measured for the **same part** of the circuit at the same time; their product is the power consumed in **that part** of the circuit alone. The following example illustrates the use of the equation.

Example 4. A generator G, Fig. 75, is furnishing a current of 4 amperes to the line at a pressure of 120 volts. There is in the circuit a resistance R, which requires 5 volts to force the current through it, and a motor M, which requires 115 volts. How much power does the resistance R consume, and how much does the motor M consume?

The resistance R consumes:

$$\text{Watts} = \text{amperes} \times \text{volts.}$$

That is,

$$\text{watts (in } R) = \text{amperes (through } R) \times \text{volts (across } R).$$
$$4 \times 5 = 20 \text{ watts.}$$

The motor consumes:

$$\text{Watts} = \text{amperes} \times \text{volts.}$$

That is,

$$\text{watts (in } M) = \text{amperes (through } M) \times \text{volts (across } M)$$
$$= 4 \times 115 = 460 \text{ watts.}$$

The power consumed by R and the motor together

$$= 20 + 460 = 480 \text{ watts,}$$

or, combining the above into one equation,

$$\text{watts} = \text{amperes} \times \text{volts.}$$
$$\text{Watts (in both } M \text{ and } R)$$
$$= \text{amperes (through both)} \times \text{volts (across both).}$$
$$4 \times 120 = 480 \text{ watts.}$$

This checks with the value of power, 480 watts, obtained by adding the power consumed by each.

When the voltage and current for each part of a circuit are not given, they can be found by applying Ohm's Law to that part of the circuit, and then applying the power equation to find the watts consumed.

Example 5. What power is consumed by an incandescent lamp of 200 ohms resistance, when burning on a 110-volt circuit?

First Step. (Find amperes and volts.)

$$\begin{aligned} \text{Amperes} &= \frac{\text{volts}}{\text{ohms}} \\ &= \tfrac{110}{200} \\ &= 0.55 \text{ amp.} \end{aligned}$$

Second Step. (Compute power.)

$$\begin{aligned} \text{Watts} &= \text{amperes} \times \text{volts} \\ &= 0.55 \times 110. \\ \text{Power} &= 60.5 \text{ watts.} \end{aligned}$$

Prob. 17. The generator *G*, Fig. 76, furnishes 1.5 amp. to the line at 125 volts pressure. What power is consumed:
(*a*) By the 110-volt lamp *L*, and
(*b*) By the 10-ohm resistance *R*?

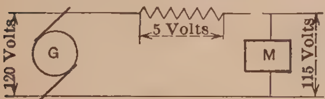


FIG. 75.

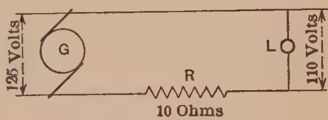


FIG. 76.

Prob. 18. What power does a car heater use if its resistance is 200 ohms and the pressure across it is 550 volts?

Prob. 19. What power does an electric flatiron use on a 115-volt circuit if its resistance is 50 ohms?

Prob. 20. A 110-volt arc lamp requires 7 amperes to operate properly. What power does such a lamp take?

Prob. 21. What power is consumed by each lamp in the group of lamps shown in Fig. 70?

Prob. 22. A heater has a resistance of 40 ohms and takes a current of 2.7 amp. What power does it consume?

Prob. 23. A telegraph line has 2000 ohms resistance. What power is consumed when 0.004 amp. is sent through it?

31. Line Loss. Since it requires power to keep a current flowing, there must be some power used in keeping the current flowing through the line wires of any system. Of course, all the power used in this way is wasted and it is, therefore, called the **Line Loss.** Line loss is measured in watts just as any other electrical power, and is the product of the volts times the amperes, **of the line wires alone.** That is,

watts (lost in line) = volts (used in line wires)
× amperes (through line wires).

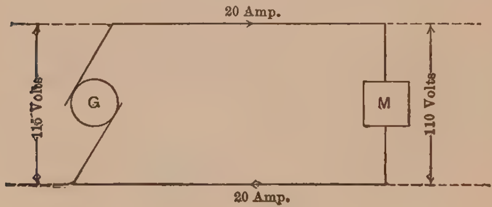


FIG. 76a.

Consider Fig. 76a. Since the generator supplies 115 volts and the motor gets only 110 volts, 5 volts must be used in forcing the current through the line.

Watts (lost in line wires) = volts (used in line wires)
× amperes (through line wires).

$$5 \times 20 = 100 \text{ watts.}$$

Or, consider the problem in this manner.

The generator (*G*) is supplying 20 amp. at 115 volts to the system. The motor (*M*) is taking 20 amp. at 110 volts. Thus,

generator supplies $20 \times 115 = 2300$ watts,
motor takes $20 \times 110 = 2200$ watts.
There must be lost in line 100 watts.

This value of the **line loss** checks with the first way of finding it.

Prob. 24. How many watts are consumed in the lead wires in Fig. 48 if their resistance is 2 ohms each?

Prob. 25. How many watts are used by the motor M in Fig. 70? How many watts by the line wires between G and M?

32. Kilowatt and Horse Power. Since the watt is a unit of power too small to conveniently express the output of modern electrical machinery, a unit called the **Kilowatt,** equal to 1000 watts, is generally used.

Thus:

2500 watts would be $\frac{1}{1000}$ of 2500, or 2.5 kw.
and 450 " " " $\frac{1}{1000}$ " 450, " 0.45 "

Example 6. What power does a motor consume which takes 20 amperes at 220 volts?

$$\text{Watts} = 20 \times 220$$
$$= 4400 \text{ watts.}$$
$$\text{Kilowatts} = \frac{4400}{1000} = 4.4 \text{ kw.}$$

Since a kilowatt is a unit of power it can be reduced to horse power.

$$1 \text{ kilowatt} = 1\tfrac{1}{3} \text{ horse power,}$$
or
$$1 \text{ horse power} = \tfrac{3}{4} \text{ kilowatt.}$$

Example 7. What horse power does the motor of the above example consume?

$$1 \text{ kw.} = 1\tfrac{1}{3} \text{ h.p.}$$
$$4.4 \text{ kw.} = 4.4 \times 1\tfrac{1}{3} \text{ h.p.}$$
$$= 5.87 \text{ h.p.}$$

Example 8. The power of a 10-horse power motor could be rated as how many kilowatts?

$$1 \text{ h.p.} = \tfrac{3}{4} \text{ kw.}$$
$$10 \text{ h.p.} = 10 \times \tfrac{3}{4} \text{ kw.}$$
$$= 7.5 \text{ kilowatts.}$$

Prob. 26. What power in kilowatts and in horse power does a 115-volt lamp consume when it takes 0.6 amp. current?

Prob. 27. Express the answer to Problem 17 in kw. and h.p.

Prob. 28. " " " " " 18 " " " "

Prob. 29. " " " " " 20 " " " "

Prob. 30. " " " " " 22 " " " "

33. Efficiency of Electrical Apparatus. No electrical machine gives out all the power it receives. The percentage which it does give out is called its **efficiency.** Thus a motor that gives out 9 kw. for every 10 kw. it receives, is said to have an efficiency of 90 per cent. If it gives out only 8 kw. for every 10 kw. it receives, it has an efficiency of only 80 per cent.

The power a machine receives is called the **input.** The power it gives out is called the **output.** The efficiency may be said to be the ratio of the output to the input, or

$$\textbf{efficiency} = \frac{\textbf{output}}{\textbf{input}}.$$

Since the output is always smaller than the input, the fraction $\frac{\text{output}}{\text{input}}$ is always less than unity, and is stated as a percentage, as 75 per cent, 90 per cent, etc. Another way of stating the same fact is: The efficiency of any device is always less than 100 per cent. Of course, the output and the input must always be stated in the same units. We cannot compare the input of a motor in kilowatts to the output in horse power. They must both be reduced either to kilowatts or to horse power.

Example 9. A 5-h.p. motor takes 4.8 kw. to operate it. What is the efficiency of the motor?

Reduce both output and input to horse power.

$$4.8 \text{ kw.} = 4.8 \times 1\tfrac{1}{3} = 6.4 \text{ h.p.}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$= \frac{5}{6.4} = 78.2 \text{ per cent,}$$

or

reduce both output and input to kilowatts.

$$5 \text{ h.p.} = \tfrac{3}{4} \times 5 = 3.75 \text{ kw.}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$= \frac{3.75}{4.8} = 78.2 \text{ per cent.}$$

Prob. 31. A motor having an efficiency of 80 per cent takes 2 kw. What h.p. will it deliver?

Prob. 32. What power in kilowatts is required to operate a 10-h.p. motor having an efficiency of 90 per cent?

Prob. 33. What current will the motor of Problem 31 require if the motor is built for 115 volts?

Prob. 34. For what voltage is the motor of Problem 32 built if it requires 6.75 amp.?

Prob. 35. A 110-volt motor taking 19 amperes has an efficiency of 85 per cent. What horse power will it deliver?

Prob. 36. What current does a 1-h.p., 110-volt motor take if its efficiency is 70 per cent?

Prob. 37. An engine supplies 180 h.p. to a generator delivering 210 amp. at 550 volts. What is the efficiency of the generator?

Prob. 38. A generator delivers a current of 60 amp. at a pressure of 110 volts. What power does it supply in kilowatts? In horse power?

Prob. 39. An engine supplies 160 h.p. to a generator delivering 185 amp. at a pressure of 550 volts. What is the efficiency of the generator?

34. Work and Energy. Horse Power-hour. Kilowatt-hour. When a man buys mechanical power to run his shop he has to pay not only according to the horse power he uses but also according to the number of hours he uses the power. For instance, he may use 40 horse power for 1 hour and pay $1.20 for it, that is, at the rate of 3 cents for each horse power-hour. If he uses 40 horse power for 2 hours he would have to pay twice as much, because he has used the same power twice as long. Another way of stating the same fact is to say that he used twice as many horse power-hours. For in the first instance he used 40 × 1, or 40 horse power-hours, and in the second 40 × 2, or 80 horse power-hours. In other words, he did twice as much work in the second case as he did in the first, or received twice as much energy. The unit of work or energy then is the **horse power-hour,** and is the work done in one hour by a one-horse power machine.

Example 10. How much work is done by a machine delivering 15 h.p. when it is run for 8 hours?

1 h.p. in 1 hr. does 1 h.p-hr.,
15 h.p. " 1 hr. " 15 h.p-hr.,
15 h.p. " 8 hr. " 8 × 15, or 120 h.p-hr.,

or work = horse power × hours,

15 × 8 = 120 h.p-hr.

Example 11. At 3 cents per horse power-hour how much does it cost to run a 200-h.p. engine for 12 hours?

Horse power-hours = 200 × 12
= 2400 h.p-hours.
Cost = 3 cents × 2400 = $72.00.

Prob. 40. What does it cost to run a 15-h.p. engine for 120 hrs. at $1\frac{1}{2}$ cents per h.p-hr.?

Prob. 41. A man's bill for 38 hours was $24.00. If he paid at the rate of 2 cents per h.p-hr., what average power was delivered to him?

Prob. 42. A man pays 3 cents per h.p-hr. for power. How long can he use 20 h.p. and not have a bill to exceed $100.00?

Similarly, electric power is sold by the **kilowatt-hour.** This unit is the work or energy delivered in one hour by a 1-kilowatt machine.

Example 12. A generator delivers 2 kilowatts to a consumer for 40 hours. How much electrical energy is consumed by the customer?

$$\begin{aligned} \text{Kilowatt-hours} &= \text{kilowatts} \times \text{hours} \\ &= 2 \times 40 = 80 \text{ kw-hr.} \end{aligned}$$

Prob. 43. How much electrical energy is consumed in 40 hours by a motor which requires 15 kw.?

Prob. 44. What will be the cost of using 48 kw. for 30 hours at 10 cents per kw-hr.?

Prob. 45. For how many hours can a 200-kw. motor be run on $50.00? Electrical energy costs $2\frac{1}{2}$ cents per kw-hr.

35. Watt-hour Meter. An instrument for measuring the electrical energy delivered to a customer is shown in Fig. 77. It is merely a small electric motor so arranged that the dials register the number of kilowatt-hours which pass through it. For a description of this instrument and a detailed explanation of the principle upon which it operates, see Chapter IX and the author's "Elements of Electricity."

Since kilowatt-hours are made up of hours and kilowatts, which in turn are made up of volts and amperes, it is always possible to find the electric energy when the **volts, amperes** and **hours** are known. Thus:

How much electrical energy is taken in 10 hours by a 110-volt motor which takes 6 amp.?

$$\begin{aligned} \text{Watts} &= \text{volts} \times \text{amperes} \\ &= 110 \times 6 = 660 \text{ watts} \\ &= 0.66 \text{ kw.} \\ \text{Kw-hr.} &= \text{kilowatts} \times \text{hours} \\ &= 0.66 \times 10 = 6.6 \text{ kw-hr.} \end{aligned}$$

Prob. 46. How much will it cost at 4 cents per kw-hr. to run a 110-volt motor for 8 hours? Motor takes 50 amperes.

Prob. 47. How much work is done when a 60-watt lamp is burned for 14 hours?

Prob. 48. At 12 cents per kilowatt-hour, what is the cost of running the iron in Problem 12 for 6 hours?

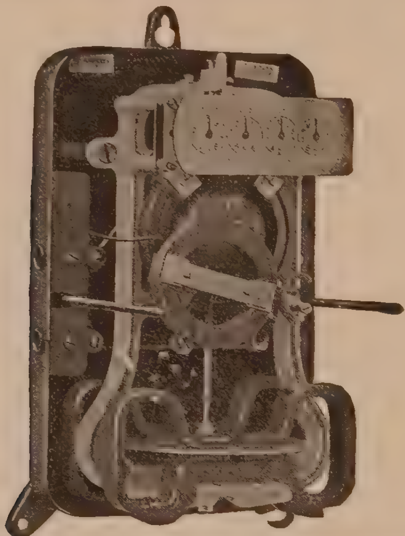


FIG. 77. Interior of General Electric Thomson watt-hour meter.

Prob. 49. What work is done in maintaining for 12 hours a current of 100 amperes in a wire of 1.8 ohm resistance?

Prob. 50. A bill for electric energy was $16.40 for 120 hours. If the price was 12 cents per kw-hr., what was the average power used?

Prob. 51. When 100 incandescent lamps had been burned on a 110-volt circuit for 4 hours, a bill of $4.00 was presented, computed at the rate of 20 cents per kw-hr. What was the average current taken by each lamp?

Prob. 52. At 3 cents per kw-hr., how much does it cost per year for transmission losses in Fig. 69? Lamps are burned 2 hours each day.

Prob. 53. What is the total energy lost in the line wires per month of 100 hours in Fig. 67?

Prob. 54. At 11 cents per kw-hr. how long can two 110-volt tungsten lamps be burned for $1.00. Resistance of each lamp is 250 ohms.

SUMMARY OF CHAPTER IV

WATT is the small unit of electric power; power in watts equals volts × amperes.

KILOWATT equals 1000 watts; equals $1\frac{1}{3}$ horse power.

HORSE POWER equals $\frac{3}{4}$ kilowatt.

POWER (in watts) consumed by any part of a circuit equals the product of the current flowing through THAT PART of the circuit times the voltage across JUST THAT SAME PART of the circuit.

EFFICIENCY is the fraction of the power put into a machine which can be delivered by machine. This is expressed as a percentage. Since a machine never delivers all the power put into it, this is always less than 100 per cent.

ENERGY AND WORK. Mechanical energy is measured commercially by the horse power-hour; equals (horse power) × (hours).

Electrical energy is measured commercially by the kilowatt-hour: equals (kilowatts) × (hours).

PROBLEMS ON CHAPTER IV

Prob. 55. What is the cost of burning for 6 hours, five 50-watt lamps? Price of electric energy is 12 cents per kw-hr.

Prob. 56. A 16-candle-power lamp is rated at 3 watts per candle-power. What will it cost to burn the lamp 100 hours at 15 cents per kw-hr.?

Prob. 57. What is the cost of burning, per month of 150 hours, three 20-candle-power lamps which are rated at $1\frac{1}{2}$ watts per candle-power? Electricity costs 10 cents per kw-hr.

Prob. 58. How many 50-watt lamps can be burned for a month of 120 hours and not cost over $2.00? (Electricity at 12 cents per kw-hr.)

Prob. 59. What efficiency has an 8-horse power motor which requires 65 amperes at 112 volts?

Prob. 60. A generator has an efficiency of 90 per cent. What current can it deliver at a pressure of 220 volts when it receives 100 h.p. from the driving engine?

Prob. 61. What is the efficiency of a 2.5-h.p. motor if the input is 2.5 kw.?

Prob. 62. The lamp bank *A*, Fig. 78, uses 6 amperes.

(*a*) What power is lost in the line?

(*b*) What power is used by each lamp?

(*c*) What power is delivered by generator?

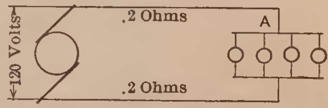


FIG. 78

Prob. 63. The efficiency of the generator in Problem 62 is 95 per cent. How much power does it receive? (Answer to be in horse power.)

FIG. 79

Prob. 64. Electrical energy for lighting costs 15 cents per kw-hr. What is the cost per month (30 days) of operating a 16-c-p. lamp, which takes 3.1 watts per candle-power, the lamp being in service 3 hours each day?

Prob. 65. Electrical energy is supplied at 5 cents per kw-hr. for driving a 25-h.p. motor. The efficiency of the motor at full load is 85 per cent. Find the cost of operating the motor for 100 hours.

Prob. 66. The voltage across terminals of the arc lamp in Fig. 79 is 110 volts. If the arc takes 10 amperes at 85 volts and gives 800 c-p.

(*a*) What power is consumed by the series resistance *R*?

(*b*) How many watts per c-p. are taken by the lamp?

Prob. 67. The generator, Fig. 80, delivers 6 kw. to the line. The motor uses 5.7 kw.

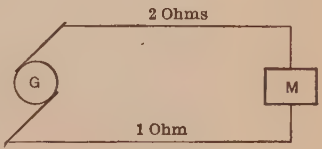


FIG. 80

Find:

(*a*) Watts lost in line.

(*b*) Voltage and current of motor.

(*c*) Brush potential of generator.

Prob. 68. An iron wire is to be used as an electric heater. The wire has a resistance of 0.004 ohm per foot. How many feet of wire must be used to absorb 2.4 kw., if the wire is to carry 25 amp.?

Prob. 69. A motor takes 12 kw. The resistance of the lead wires is 0.08 ohm each.

(*a*) How much power is lost in the leads if the voltage of the motor is 110 volts?

(*b*) If the voltage of the motor is 220 volts?

Prob. 70. What must be the pressure at the generator in Problem 69 (*a*) and (*b*)?

Prob. 71. At 4 cents per kw-hr., how much is the energy worth which is lost per year of 300 days of 10 hours each, in the lead wires of Problem 69 (*a*) and (b)?

Prob. 72. What does it cost to run an electric car a mile, if 60 amp. at 550 volts drive a car at an average rate of 15 miles per hour? (Electricity to cost 2 cents per kw-hr.)

Prob. 73. What does it cost at 11 cents per kw-hr. to use eight 16-c-p. incandescent lamps for 6 hours, if each lamp takes 3 watts per c-p.?

Prob. 74. How large a generator is needed to supply a current of 0.6 amp. at 112 volts to each of 500 lamps?

CHAPTER V

WIRE AND WIRING SYSTEMS

Copper wire is generally used for the conductors in an electric circuit, on account of its low resistance as compared with other materials. A round copper wire $\frac{1}{10}$ inch in diameter has a resistance of but 1 ohm per 1000 ft. while an iron wire of the same size has a resistance of about 6 ohms per 1000 ft.

It is necessary to compute the resistance of given lengths of any size copper wire in order to know in advance what the loss in voltage along it is going to be. Thus, it is necessary to know what effect length and diameter have upon the resistance.

36. Effect of Length. The effect of length is very readily understood. For instance, if we should take 2000 ft. of $\frac{1}{10}$-inch wire instead of 1000 ft. as mentioned above, we should find that it had 2 ohms resistance instead of 1 ohm. Similarly, 500 ft. would have $\frac{1}{2}$ ohm. The resistance of a given size of copper wire then depends directly upon its length. If we know the resistance of 1 ft. of a certain size wire we can find the resistance of any length of that size by merely multiplying the resistance per foot by the length.

Example 1. The resistance of 1 ft. of copper wire $\frac{1}{100}$ inch in diameter is 0.103 ohm. What is the resistance of 400 ft.?

$$\begin{aligned} \text{Resistance of } \quad 1 \text{ ft.} &= 0.103 \text{ ohm}, \\ \text{“} \qquad \text{“ } 400 \text{ “} &= 400 \times 0.103 \\ &= 41.2 \text{ ohms.} \end{aligned}$$

Prob. 1. What is the resistance of 1000 ft. of the wire in the above example?

Prob. 2. The resistance of 1 ft. of a certain size wire is 0.082 ohm. How many feet of this wire will it take to make a resistance of 25 ohms?

Prob. 3. If the resistance of 900 ft. of a certain size wire is 0.223 ohm, what is the resistance of 2000 ft.?

37. The Effect of Size. The effect of increasing or decreasing the size is a little more difficult to understand.

Let us assume for a moment that copper wires are drawn square instead of round. Assume a certain square wire to

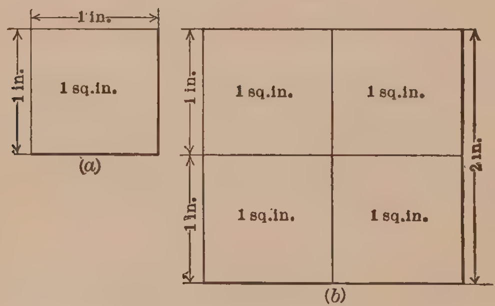


FIG. 81. The side of (*b*) is twice the side of (*a*) but the area of (*b*) is 4 times the area of (*a*).

measure 1 inch on each side. The area of the end of the wire (generally called the "cross-section area") would then be 1 square inch.

If we take a square wire 2 inches on each side, its cross-section area would be 2 × 2, or 4 square inches. Thus (*a*), Fig. 81, represents the end view of a square wire 1 inch on a side, while (*b*) represents the end view of a wire 2 inches on a side.

Note that although the side of (*b*) is only **twice** as great as that of (*a*), the area of (*b*) is **four** times that of (*a*). In other words, four 1-inch wires could be made out of a

2-inch wire. The figure clearly shows that the 2-inch wire contains enough material to make four 1-inch wires.

In the same way it will be seen that if we make a square wire 3 inches on a side, the area of the end will be 3 × 3, or 9 square inches. A wire 3 inches on a side will then make 9 wires 1 inch on a side. Similarly a 5-inch wire will make 25 wires 1 inch on a side, etc.

Note that in each case as we increase the length of the side a given number of times, we increase the end area the **square of that number of times,** and the number of small wires that the larger one is equivalent to, is also the **square** of that number.

Thus:

(*a*) A 2 in.-wire has 4 sq. in. area and is equal to 4 1-in. wires.
(*b*) A 3 " " " 9 " " " " " " " 9 1-in. wires.
(*c*) A 4 " " " 16 " " " " " " " 16 1-in. wires.
etc.

If we had a square copper wire 1 ft. long and $\frac{1}{100}$ inch on a side, it would have a resistance of 0.081 ohm.

Now if we had a square copper wire 1 ft. long but $\frac{2}{100}$ inch on a side, it would make 4 wires 1 ft. long and $\frac{1}{100}$ inch on a side, since it would have twice the length of side of the $\frac{1}{100}$-inch wire. Thus the $\frac{2}{100}$-inch wire is equivalent to four $\frac{1}{100}$-inch wires 1 ft. long laid side by side. This would be equivalent to placing four $\frac{1}{100}$-inch wires 1 ft. long in parallel. So the resistance of 1 ft. of $\frac{2}{100}$-inch sq. wire is equal to the resistance of four $\frac{1}{100}$-inch wires each one ft. long placed in parallel, as is shown in Fig. 82.

An electric current could then go through the larger wire **four** times as easily as through the smaller wire. In other words, the **resistance** is only **one fourth** as much, as we have seen on page 39.

Thus, if the resistance of 1 ft. of $\frac{1}{100}$-inch square copper

wire is 0.081 ohm, the resistance of 1 ft. of $\frac{2}{100}$-inch square copper wire would be $\frac{0.081}{4} = 0.0203$ ohm. Similarly, the resistance of 1 ft. of $\frac{3}{100}$-inch square copper wire would be $\frac{0.081}{9} = 0.009$ ohm, etc.

Note that if we know the resistance of a foot of any square wire of unit length of side, we can find the resistance of a foot of square wire of any length of side, by **dividing** by the **square** of the number of these units in the side. This amounts to dividing the resistance of the unit wire by the number of unit wires of which this wire may be assumed to be composed.

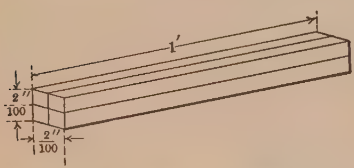


FIG. 82. One wire 2 in. square makes four wires 1 in. square.

Example 2. Assume a square unit wire $\frac{1}{1000}$ inch on a side and 1 ft. long, has a resistance of 8.16 ohms. What would be the resistance of a square wire 1 ft. long and $\frac{8}{1000}$ inch on a side?

Resistance of 1 ft. of wire $\frac{1}{1000}$ inch on a side $= 8.16$ ohms,

" " 1 ft. " " $\frac{8}{1000}$ " " " $\frac{8.16}{(8)^2} = \frac{8.16}{64}$ "

$= 0.127$ ohm.

For a wire $\frac{8}{1000}$ inch on a side is equivalent to 8×8, or 64 wires $\frac{1}{1000}$ inch on a side, laid side by side, or in parallel. The resistance of an $\frac{8}{1000}$-inch wire therefore equals $\frac{1}{64}$ of 8.16 ohms $= 0.127$ ohm.

Example 3. On the basis of Example 2 what would be the resistance of a square copper wire 0.415 inch on a side?

$$0.415 = \frac{415}{1000}.$$

Thus, this wire would be equal to 415 × 415, or 172,000 wires $\frac{1}{1000}$ in. on a side, laid in parallel.

Resistance of 0.415-inch wire then equals

$$\frac{8.16}{172{,}000} = 0.0000474 \text{ ohm},$$

or

A square wire $\frac{1}{1000}$ in. on a side has 8.16 ohms resistance,
" " " $\frac{415}{1000}$ " " " $\dfrac{8.16}{415 \times 415} = 0.0000474$ ohm.

Prob. 4. Assuming the resistance of a unit square wire as in Example 2, what is the resistance of 1 ft. of square copper wire 0.035 inch on a side?

Prob. 5. On the same basis, what is the resistance of 1 ft. of square copper wire $\frac{2}{100}$ inch on a side?

Prob. 6. On the same basis, what must be the length of side of 1 ft. of square copper wire, to have a resistance of 0.0627 ohm?

38. Circular Wire. As most copper wire is drawn round instead of square, we must be able to compute the resistance of such wire.

It may be said at once that all statements concerning square wire apply equally to round wire. That is:

(1) The resistance of any length of round wire is equal to the resistance of one foot of that wire multiplied by the length in feet.

(2) If the resistance of one foot of round copper wire $\frac{1}{1000}$ inch in diameter is known, then the resistance of one foot of any size round wire is equal to this known resistance divided by the **square** of the number of thousandths in the diameter.

The first statement is obvious; the second requires corroboration.

We have seen how a square wire 3 inches in diameter is equal to 3 × 3, or 9 square wires 1 inch in diameter, laid

side by side. Similarly, a round wire 3 inches in diameter is equal to 3 × 3, or 9 round wires 1 inch in diameter, laid side by side.

Thus, in Fig. 83 it can be shown that the 3-inch circle has exactly the same area as the **nine** 1-inch circles combined, and will contain **nine** 1-inch circles, if we consider that the parts projecting beyond the large circle are to be used up

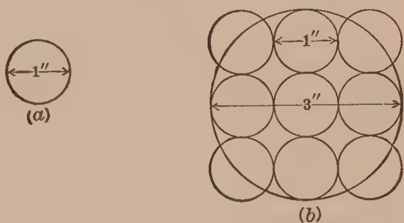


FIG. 83. The diameter of (*b*) is 3 times the diameter of (*a*) but the area of (*b*) is 9 times the area of (*a*).

in filling in the chinks left inside the large circle. Therefore, the large circle can be thought of as being composed of small circles of unit diameter. There are as many small circles in the large one as the square of the diameter of the large one. Accordingly, a round wire $\frac{5}{1000}$ inch in diameter is equal to 5 × 5, or 25 round wires $\frac{1}{1000}$ inch in diameter laid side by side, or in parallel. If we knew the resistance of the $\frac{1}{1000}$-inch wire, then we would know that the resistance of the $\frac{5}{1000}$-inch wire was $\frac{1}{25}$ of the resistance of the $\frac{1}{1000}$-inch wire.

The mathematical proof of the fact that a circle 3 inches in diameter contains the area of 9 circles, 1 inch in diameter, is as follows:

Area of circle 1 inch in diam. = 0.7854 × 1 × 1 = 0.7854 sq. in.
" " " 3 " " " = 0.7854 × 3 × 3 = 7.069 " "

There are then as many circles 1 inch in diameter in a circle 3 inches in diameter as

0.7854 sq. in. is contained in 7.069 sq. in., or 9.

Therefore a circle 3 inches in diameter contains

3×3, or 9 circles 1 inch in diameter.

In the same way it can be proved that a 5-inch circle contains 5×5, or 25 1-inch circles, etc.

39. Mil. A round wire 1 ft. long and $\frac{1}{1000}$ inch in diameter has been adopted as the unit round wire. The diameter $\frac{1}{1000}$ inch is called a **mil.** The term "mil" always means $\frac{1}{1000}$. In our coinage a "mill" is $\frac{1}{1000}$ of a dollar. A millivolt is $\frac{1}{1000}$ volt, etc. When it is spelled "mil" it always means $\frac{1}{1000}$ inch. Thus a wire of 1 mil in diameter is a wire $\frac{1}{1000}$ inch in diameter. A wire 25 mils in diameter is $\frac{25}{1000}$ inch in diameter, etc. Instead of saying "thousandth inch" we say "mil" in speaking of the diameter of wire.

Prob. 7. How many mils in 0.428 inch?

Prob. 8. A wire has a diameter of 0.046 inch. What is the diameter in mils?

Prob. 9. What is the diameter in mils of a wire 1.4 inch in diameter?

Prob. 10. A wire has a diameter of 75 mils. What is its diameter in inches?

40. Mil-foot. Circular Mil. The unit wire is a round wire 1 ft. long and 1 mil in diameter, and is called a **mil-foot** wire.

Now we have found that a wire of more than $\frac{1}{1000}$ inch or 1 mil in diameter will contain as many unit wires as the square of the number of mils or thousandths in its diameter. Thus, a wire 8 mils in diameter is equivalent to 64 wires 1 mil in diameter. Another way of saying this is to say that the end area of a round wire 1 mil in diameter is 1 **circular mil**, to distinguish it from a square wire. Then the end

area of a wire $\frac{8}{1000}$ inch in diameter would be 8×8, or 64 circular mils.

The circular mil area of a wire, then, is the number of unit circles which it will contain, a unit circle being a circle 1 mil in diameter. Since any circle will contain as many unit circles as the square of the diameter in mils, we say that the area of a circle in circular mils equals the square of the diameter in mils.

Thus, the area of a circle 4 mils in diam. is $4 \times 4 = 16$ cir. mils.
Area of circle 60 mils in diam. is $60 \times 60 = 3{,}600$ cir. mils,
" " " 250 " " " " $250 \times 250 = 62{,}500$ " "
etc.

This method of stating the area of a circle is much easier and more sensible than finding the area in square inches, which always involves the value 3.1416. It is merely finding the number of unit circles contained in a circle, instead of the number of unit squares. The number of unit squares in a circle never comes out even, but the number of unit circles (circular mils) is always the square of the diameter in mils.

Example 4. What is the area in circular mils of a circle $\frac{1}{2}$ inch in diameter?

$$\tfrac{1}{2} \text{ inch} = \frac{500}{1000} \text{ in.} = 500 \text{ mils.}$$

$$\text{Area} = 500 \times 500 = 250{,}000 \text{ circular mils.}$$

Example 5. How many unit wires would 1 ft. of wire $\frac{1}{4}$ in. in diameter contain?

$$\tfrac{1}{4} \text{ in.} = \frac{250}{1000} = 250 \text{ mils.}$$

$$\text{Area} = 250 \times 250 = 62{,}500 \text{ cir. mils.}$$
$$\text{Area of unit wire} = 1 \text{ cir. mil.}$$

$$\text{Wire of } 62{,}500 \text{ cir. mils then contains } \frac{62{,}500}{1} = 62{,}500 \text{ unit wires.}$$

Prob. 11. What is the cir. mil area of a wire 0.046 inch in diameter?

Prob. 12. What is the cir. mil area of wire 0.02 inch in diameter?

Prob. 13. Find the cir. mil area of a circle 0.416 inch in diameter.

Prob. 14. How many unit wires will a wire $\frac{1}{10}$ inch in diameter make?

Prob. 15. To how many unit wires is a wire 1 inch in diam. equivalent?

Prob. 16. What is the diameter of a wire containing 1600 cir. mils?

Prob. 17. What is the diameter of a wire containing 22,500 cir. mils?

Prob. 18. What area in circular mils will a circle 2.04 inches in diameter have?

41. Effect of Length and Diameter upon the Resistance of Wire. We have defined a unit wire as a round wire 1 ft. long and 1 mil in diameter (or having an end area of 1 circular mil). This unit wire is called a mil-foot and when made of copper has a resistance of 10.4 ohms. This is usually stated as follows:

The resistance per mil-foot of copper is usually taken as 10.4 ohms. This statement should be memorized carefully as all calculations of copper wire are based on it, and from it we may compute the resistance of any length of any size copper wire.

For if we know the resistance of 1 ft. of round wire 1 mil in diameter, then we can compute the resistance of 1 ft. of any size round wire as follows:

To find the resistance of 1 ft. of copper wire $\frac{6}{1000}$ inch in diameter, we say that the resistance of 1 ft. of copper wire having 1 mil diameter is 10.4 ohms. A wire having $\frac{6}{1000}$ inch, or 6 mils, diameter is equivalent to 6×6, or 36 wires 1 mil in diameter, laid side by side, since it con-

tains 6 × 6, or 36 cir. mils end area. The resistance then of 1 ft. of 6-mil wire would be $\frac{10.4}{36} = 0.289$ ohm,

or

$$\begin{array}{lr} \text{Resistance of 1 ft. of wire 1 mil in diam.} & = 10.4 \text{ ohms,} \\ \text{" \quad " 1 ft. " \quad " 6 " \quad " \quad "} & = \dfrac{10.4}{6 \times 6} \\ & = 0.289 \text{ ohm.} \end{array}$$

But we have seen that if we know the resistance of 1 ft. of any wire, we can find the resistance of any number of feet by simply multiplying by the length. Thus, if the resistance of 1 ft. of copper wire 6 mils in diameter is 0.289 ohm, as found above, then the resistance of 1000 ft. of this wire would be 0.289 × 1000 = 289 ohms.

Thus, to find the resistance of any length of any size wire:

> **Multiply the resistance of unit wire (1 mil-foot) by the length in feet and divide by the square of the mil diameter (circular mil area).**

Example 6. What is the resistance of one mile of copper wire 0.125 inch in diameter?

$$\begin{array}{lr} \text{Resistance of 1 ft. of wire 1 mil in diam.} & = 10.4 \text{ ohms,} \\ \text{" \quad " 1 ft. " \quad " 125 mils " \quad "} & = \dfrac{10.4}{125 \times 125} \\ & = 0.000667 \text{ ohms.} \\ \text{" \quad " 5280 ft. " \quad " 125 " \quad " \quad "} & = 0.000667 \times 5280 \\ & = 3.52 \text{ ohms,} \end{array}$$

or

$$\text{Res. of wire} = \frac{\text{resistance per mil foot} \times \text{length in feet}}{\text{cir. mil area}},$$

$$= \frac{10.4 \times 5280}{125 \times 125} = 3.52 \text{ ohms.}$$

Prob. 19. What resistance will 1000 ft. of copper wire have, if it is $\frac{4}{100}$ inch in diameter?

Prob. 20. How many feet of copper wire 0.04 inch in diameter will it take to make a resistance of 2 ohms?

Prob. 21. What will be the resistance of 900 ft. of copper wire $\frac{15}{100}$ inch in diameter?

Prob. 22. What diameter must copper wire have in order that one mile of it may have a resistance of 0.096 ohm?

Prob. 23. What is the resistance of 2 miles of 0.42 mil copper wire?

Prob. 24. What is the circular mil area of a wire $\frac{3}{16}$ inch in diameter?

Prob. 25. What resistance will 2000 ft. of copper wire of the size in Prob. 24 have?

Prob. 26. What resistance has 500 ft. of a copper wire of 9876 cir. mil area?

Prob. 27. What is the diameter of the wire in Prob. 26?

Prob. 28. What is the resistance of 4 miles of copper wire $\frac{3}{8}$ inch in diameter?

Prob. 29. How many miles of copper wire $\frac{1}{2}$ inch in diameter will it take to make 5 ohms of resistance?

Prob. 30. The distance between a motor and a generator is 800 ft. The copper line wires are 0.162 inch in diameter. What is the resistance of the line?

Prob. 31. Ordinary fixture wire usually has a diameter of 0.064 inch. What is the resistance per 1000 ft.?

Prob. 32. Annunciator wire generally has a diameter of 0.040 inch. How many feet does it take to make a resistance of 1 ohm?

Prob. 33. How many feet of the wire in Prob. 31 does it take to produce 1 ohm?

Prob. 34. The line wires in Fig. 33 are each 300 ft. long. Of what diameter must they be?

Prob. 35. How long is each line wire in Fig. 27 if each has a diameter of 0.068 inch?

Prob. 36. In Fig. 55 what size wire is used? The distance from the generator to the lamps is 400 ft.

Prob. 37. What is the resistance of 8 miles of copper wire $\frac{7}{16}$ inch in diameter?

42. Drop Along a Line Wire. Knowing the length and the size of a line wire and the current it is to carry, we are able to compute the voltage drop in the wire.

Example 7. A 2000-ft. copper line wire is 0.204 inch in diameter. What is the voltage drop in sending 40 amperes through it?

$$\begin{aligned}\text{Resistance} &= \frac{\text{resistance of unit wire} \times \text{length}}{\text{circular mils}}\\ &= \frac{10.4 \times 2000}{204 \times 204}\\ &= 0.5 \text{ ohm.}\\ \text{Volts} &= \text{ohms} \times \text{amperes}\\ &= 0.5 \times 40\\ &= 20 \text{ volts.}\end{aligned}$$

Prob. 38. How many volts are required to send 6 amp. through 400 ft. of copper wire 0.064 inch in diameter?

Prob. 39. What voltage is required to send 20 amp. through 800 ft. of copper wire 0.162 inch in diameter?

Prob. 40. A $\frac{1}{4}$ inch copper wire carries 25 amp. What is the voltage drop per mile?

Prob. 41. A copper wire carries 120 amp. for 1600 ft. If its diameter is 0.364 inch, what is the voltage drop?

Prob. 42. How many amperes can be forced through 1000 ft. of copper wire $\frac{1}{8}$ inch in diameter, with a voltage drop of 5 volts?

Prob. 43. What size copper wire must be used if 6 volts are to be used in forcing 15 amp. through 1 mile of wire?

Prob. 44. If 12 volts are used in forcing 25 amp. through a line wire $\frac{3}{16}$ inch in diameter, what is the length of the wire?

Prob. 45. The motor, Fig. 84, is 180 ft. from the generator and requires 18 amp. What size line wire must be used?

Prob. 46. How far will a pair of copper line wires transmit 40 amp. with a line drop of 8 volts, if the wire is 0.262 inch in diameter?

Prob. 47. Each arc lamp, Fig. 85, takes 6 amp. at 85 volts. The distance between lamps is 200 ft. The lamps nearest the

generator are 200 ft. from it. What size wire is used for line wires?

Prob. 48. Each lamp in Fig. 86 takes 2 amp. at 112 volts. The lamps are 500 ft. from the generator. The line wire is $\frac{1}{8}$ inch in diameter. What is the voltage of the generator?

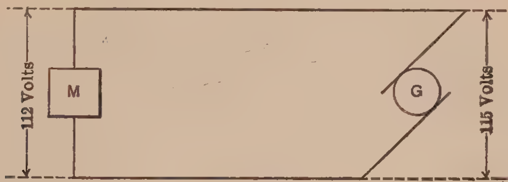


FIG. 84.

FIG. 85.

Prob. 49. A copper wire is 500 ft. long and 0.238 in. in diameter. How many volts will it take to send 15 amp. through it?

Prob. 50. What will be the drop per mile in a line consisting of copper wire $\frac{1}{16}$ inch in diameter carrying 36 amp.?

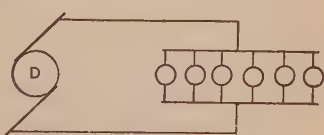


FIG. 86.

Prob. 51. What will be the line drop in voltage and loss in watts per mile in transmitting 12 kw. at 550 volts, if a copper wire is used having a diameter of 0.364 inch?

Prob. 52. A group of incandescent lamps takes 12 amp. The line drop is not to exceed 2.6 volts. What must be the size of the copper wire to be used if the lamps are 2500 ft. from the generator?

Prob. 53. A 220-volt, 25-h.p. motor of 90% efficiency is situated 500 ft. from the generator. Copper wire 0.460 inch in diameter is used for the line. What must be the voltage of the generator?

Prob. 54. What size wire might have been used in Prob. 53 if a line drop of 4% of the voltage of the generator had been desired?

Prob. 55. What size of copper wire is required between a 115-volt generator and a 110-volt, 7.5-h.p. motor of 85% efficiency? The motor and generator are 1800 ft. apart.

Prob. 56. What power is lost in a mile line if the wire is 0.22 inch in diameter and carries 24 amp.?

Prob. 57. A building situated 2200 ft. from a 115-volt generator, is to be supplied with sufficient current from the generator to light 400 lamps in multiple, each taking 0.45 amp. Four per cent of the power generated is lost in the line wires. What size copper wire must be used?

43. Copper Wire Table. Wire manufacturers make up certain sizes only of copper wire. These sizes are arranged according to a scale called a **Wire Gauge.** In this country the Brown & Sharpe (B. & S.) Gauge is the standard. If any size other than a standard gauge is demanded, the manufacturers will make it, though at an increased cost.

The standard sizes are listed in a table as follows: The first column contains the gauge numbers, of which the even numbers only are in general use except in the very small sizes. The second column shows the diameter in mils of each gauge number. The third gives the end area in circular mils, which we have seen is the square of the diameter in mils. The fourth, the resistance per thousand feet. Sometimes other columns are added, giving the resistance per mile, the weight per ohm, ohms per pound, etc. Tables of this nature are to be found in the Appendix.

Resistance of Soft or Annealed Copper Wire

B. & S. gauge, No.	Diameter in mils, d	Area in circular mils, d^2	Ohms per 1000 ft. at 20° C. or 68° F.	B. & S. gauge, No.	Diameter in mils, d	Area in circular mils, d^2	Ohms per 1000 ft. at 20° C. or 68° F.
0000	460.00	211,600	0.04893	21	28.462	810.10	12.78
000	409.64	167,810	0.06170	22	25.347	642.40	16.12
00	364.80	133,080	0.07780	23	22.571	509.45	20.32
0	324.86	105,530	0.09811	24	20.100	404.01	25.63
				25	17.900	320.40	32.31
1	289.30	83,694	0.1237	26	15.940	254.10	40.75
2	257.63	66,373	0.1560	27	14.195	201.50	51.38
3	229.42	52,634	0.1967	28	12.641	159.79	64.79
4	204.31	41,742	0.2480	29	11.257	126.72	81.70
5	181.94	33,102	0.3128	30	10.025	100.50	103.0
6	162.02	26,250	0.3944	31	8.928	79.70	129.9
7	144.28	20,816	0.4973	32	7.950	63.21	163.8
8	129.49	16,509	0.6271	33	7.080	50.13	206.6
9	114.43	13,094	0.7908	34	6.305	39.75	260.5
10	101.89	10,381	0.9972	35	5.615	31.52	328.4
11	90.742	8,234.0	1.257	36	5.000	25.00	414.2
12	80.808	6,529.9	1.586	37	4.453	19.82	522.2
13	71.961	5,178.4	1.999	38	3.965	15.72	658.5
14	64.084	4,106.8	2.521	39	3.531	12.47	830.4
15	57.068	3,256.7	3.179	40	3.145	9.89	1047
16	50.820	2,582.9	4.009				
17	45.257	2,048.2	5.055				
18	40.303	1,624.3	6.374				
19	35.890	1,288.1	8.038				
20	31.961	1,021.5	10.14				

Note. To approximate the gauge number and resistance of a certain wire of known diameter, it is well to memorize the following fact.

No. 10 wire is practically $\frac{1}{10}$ inch (100 mils) in diameter (10,000 circular mils area) and has practically 1 ohm per 1000 ft. As the wires grow smaller, every third gauge number **halves** the end area, and **doubles** the resistance. For instance, No. 13 has about 5000 cir. mils area, and 2 ohms resistance; No. 16 has 2500 cir. mils area, and 4 ohms per 1000 ft., etc. As the wires increase in size, every third gauge number doubles the cir. mils area and halves the resistance; No. 7, for instance, has practically 20,000 cir. mils, and 0.5 ohm per 1000 ft., etc.

The use of these tables greatly simplifies all wire computations.

Example 8. It is required to find the resistance of 4000 ft. of copper wire 0.144 inch in diameter.

By use of the table, No. 7 wire is seen to have a diameter of practically 144 mils and a resistance of 0.497 ohm per 1000 ft.

$$\text{Resistance of 4000 ft.} = 4 \times 0.497 = 1.988 \text{ ohms.}$$

Example 9. What size copper wire would be used if 1600 ft. of it is to have not more than 0.4 ohm?

$$\text{Resistance per 1000 ft.} = \frac{0.4}{1.6} = 0.25 \text{ ohm.}$$

From the table, No. 4 wire with a diameter of 204 mils has a resistance of 0.248 ohm per 1000 ft. and is thus the wire required.

NOTE. When the computation demands a wire of a size not in the table, always choose the size next LARGER, that is, one having a SMALLER resistance than that computed.

Example 10. It is necessary to transmit 4 kw. at 230 volts, a distance of 1 mile with a drop of 10 volts. What size wire is required?

Amperes to be transmitted:

$$\text{Amperes} = \frac{\text{watts}}{\text{volts}}$$

$$= \frac{4000}{230} = 17.4 \text{ amp.}$$

Resistance of line:

$$\text{Resistance (line)} = \frac{\text{volts (line)}}{\text{amp. (line)}}$$

$$= \frac{10}{17.4} = 0.574 \text{ ohm.}$$

A 1-mile line would have 2 wires, each 1 mile long, or 2 miles of wire in all.

Resistance of 2 miles, or 10,560 ft. = 0.574 ohm.

$$\text{Resistance per 1000 ft.} = \frac{0.574}{10.56} = 0.0544 \text{ ohm.}$$

By table, No. 0000 has a resistance of 0.0489 ohm per 1000 ft.
and No. 000 " " " " 0.0617 " " " "

Thus we would have to use No. 0000 with a diameter of 460 mils.

Prob. 58. What size, B. & S. gauge, is the wire in Prob. 50?

Prob. 59. What size, B. & S. gauge, is the wire in Prob. 51?

Prob. 60. What size, B. & S. gauge, is the wire in Prob. 52?

Prob. 61. What size, B. & S. gauge, is the wire in Prob. 55?

Prob. 62. What size, B. & S. gauge, is the wire in Prob. 57?

Prob. 63. What size copper wire must be used to transmit 30 amp. from a generator to lamps, a distance of 600 ft., with 2 volts line drop?

Prob. 64. What is the resistance per mile of No. 8 wire, B. & S. gauge?

Prob. 65. How far can 20 amp. be transmitted through a No. 6 wire, B. & S. gauge, with 4 volts line drop?

Prob. 66. What wire, B. & S., has about 2 ohms per mile?

Prob. 67. How many miles of No. 00 wire will it take to make 5 ohms?

Prob. 68. In Fig. 54 the lamps are approximately 1200 ft. from the generator. What size B. & S. wire is used?

Prob. 69. What is the length of wire in Fig. 57, if No. 14, B. & S. is used?

Prob. 70. If No. 12 wire, B. & S., were used in Prob. 69, what would the length of the line be?

Prob. 71. No. 10, B. & S. gauge is used for line wire in Fig. 78. How far is it from the generator to the lamps?

Prob. 72. What size wire is used in Fig. 33 if the motor is 450 ft. from the generator?

Prob. 73. How many feet of No. 10 wire does it take to make 1 ohm?

Prob. 74. What size wire, B. & S., would you use to transmit 50 amp. a distance of 800 ft. with 8 volts line drop?

Prob. 75. Each lamp, Fig. 87, is a 110-volt, 50-watt lamp. If the lamps are 800 ft. from the generator, what size wire, B. & S., must be used?

FIG. 87.

Prob. 76. The motor in Fig. 88 is 5 h.p., 85% efficiency. The line wires are No. 8.

(*a*) What must be the voltage of the generator?
(*b*) What kilowatt capacity must the generator have?

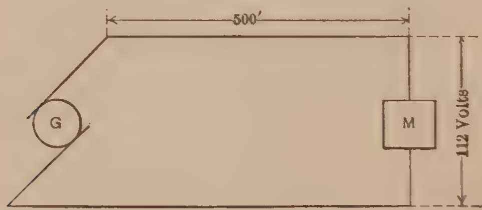


FIG. 88.

Prob. 77. In Fig. 63, Group I is 300 ft. from the generator; Group II is 480 ft. from Group I. The generator has 115 volts across its brushes. The wire used in each case is No. 6. What is the voltage across Group I, and across Group II?

Prob. 78. If the distances in Prob. 77 were twice as great, what size wire could be used for the same voltages across all points?

Prob. 79. In Prob. 17, Chap. III, No. 0 trolley wire is used. How far are the cars apart?

Prob. 80. A coil of No. 20 wire is found to have a resistance of 42 ohms. How many feet are there in the coil?

Prob. 81. A coil for an electromagnet has 800 turns of No. 23, B. & S. copper wire. The average length of a turn is 14 inches. What is the resistance of the coil?

Prob. 82. It is desired to construct a coil of not more than 290 ohms resistance. The coil must have 200 turns of about 16 in. average length. What size wire, B. & S., should be used?

Prob. 83. Each lamp, Fig. 89, takes 2 amp. at 112 volts. The motor is 110-volt, 2-h.p., 75% efficiency. What size wire must be used between the motor and lamps?

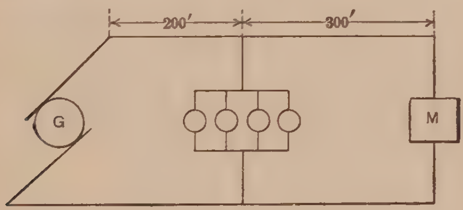


FIG. 89.

Prob. 84. If No. 4 wire is used between the lamps and generator, what is the voltage of the generator in Prob. 83?

Prob. 85. What power is lost in the line in Problems 83 and 84?

44. Stranded Wire. On account of their greater flexibility, stranded cables are very often used instead of solid wire. Such a cable is much easier to pull into conduit, and less likely to break when bent at a sharp angle. When a size of wire larger than No. 0000 is required, it is practically always made in strands rather than solid, but the smaller sizes are also very common in the stranded form.

For instance, instead of using a solid No. 4 wire, having a diameter of 204 mils and an area of 41,700 cir. mils, it is much easier to use a cable made up of 7 wires, each 0.077 inch in diameter. Each strand (wire) would then have an area of 77×77, or 5930 cir. mils. But since the cable is

made up of 7 of these strands, the area of the cable would be $7 \times 5930 = 41{,}600$ cir. mils, which is practically the area of a No. 4 solid wire.

Prob. 86. To what size wire, B. & S., is a stranded cable equivalent which is made up of 19 strands each 0.059 inch diameter?

Prob. 87. It is desired to make a cable of 19 strands which shall be equivalent to a No. 0, B. & S. solid conductor. What size strands should be used?

Prob. 88. How many strands 0.061 inch in diameter will it take to make a cable equivalent to a No. 6 wire?

Prob. 89. It is desired to make a very flexible cable equivalent to No. 4, B. & S. wire. If strands of No. 22, B. & S. wire are used, how many will be required?

Prob. 90. If 83 No. 19, B. & S. wires are used in a cable, to what size solid wire is the cable equivalent?

45. Aluminum Wire; Iron Wire, etc. Copper, on account of its low resistance, is the metal most widely used for electrical conductors. Aluminum, however, is rapidly coming into use, owing to its light weight and to improved methods of manufacture. A mil-foot of aluminum has a resistance of 18.7 ohms, while we have seen that copper has only 10.4 ohms per mil-ft. Thus an aluminum wire has nearly twice as high resistance as copper wire of the same size. A wire of a larger area, however, can be made of the aluminum, which will bring its resistance below that of the copper wire, and yet its weight will be less than that of the copper wire.

Example 11. What is the resistance of a No. 6, B. & S. aluminum wire 2000 ft. long?

A No. 6, B. & S. wire has a diameter of 162 mils.

Resistance of 1 ft. of aluminum 1 mil in diam. = 18.7 ohms,

" " 1 ft. " " 162 mils " " $= \dfrac{18.7}{162 \times 162}$

$= 0.000713$ ohm,

" " 2000 ft. " " 162 " " " $= 2000 \times 0.000713$

$= 1.426$ ohms,

or

$$\text{Resistance} = \frac{\text{resistance of unit wire} \times \text{length}}{\text{cir. mil area}}$$

$$= \frac{18.7 \times 2000}{162 \times 162}$$

$$= 1.426 \text{ ohms.}$$

Iron wire is also sometimes used for heating purposes, or where very little current is to be transmitted, as in telegraph circuits. The resistance of a mil-foot of iron wire varies according to its hardness, composition, etc., from 60 to 90 ohms. This is about seven times as high as copper. Some of the alloys of copper, nickel, zinc, manganese, chromium, etc., have a resistance of over 600 ohms per mil-foot.

Prob. 91. What resistance will a one-mile copper wire have which is $\frac{1}{4}$ inch in diameter?

Prob. 92. If the wire in Prob. 91 is of aluminum, what resistance will it have?

Prob. 93. If the wire in Prob. 91 is of iron, what resistance will it have? Use 75 as the mil-foot resistance of iron.

Prob. 94. What size aluminum wire will have the same resistance per mile as a No. 4, B. & S. copper wire?

Prob. 95. What size iron wire will have the same resistance per mile as a No. 4, B. & S. copper wire?

Prob. 96. What size iron wire will have the same resistance per mile as a No. 4, B. & S. aluminum wire?

Prob. 97. What size copper wire is equivalent to a No. 0 aluminum wire in resistance per 1000 ft.?

46. Safe Carrying Capacity for Copper Wires. It is a fact of common experience that an electric current heats the conductor through which it passes.

The filament of an incandescent lamp is made to glow by the heat generated in it. The coils of an electric heater

receive their heat from the current passing through them.

Table of Allowable Carrying Capacities of Wires

The following table, showing the allowable carrying capacity of copper wires and cables of 98% conductivity, according to the standard adopted by the American Institute of Electrical Engineers, must be followed in placing interior conductors.

For insulated aluminum wire the safe carrying capacity is 84% of that given in the following tables for copper wire with the same kind of insulation.

TABLE A		TABLE B	
Rubber Insulations		Other Insulations	
B. & S. gauge.	Amperes.	Amperes.	Circular mils.
18	3	5	1,624
16	6	10	2,583
14	15	20	4,107
12	20	25	6,530
10	25	30	10,380
8	35	50	16,510
6	50	70	26,250
5	55	80	33,100
4	70	90	41,740
3	80	100	52,630
2	90	125	66,370
1	100	150	83,690
0	125	200	105,500
00	150	225	133,100
000	175	275	167,800
0000	225	325	211,600

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulation by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

We have seen that **resistance** is in reality nothing but **electrical friction**. So, just as a bearing of a machine heats when the machine is running, an electrical conductor heats

when a current is running. We decrease the friction of a machine by using smooth surfaces of the proper metals, and then lubricating it, so that the temperature rise is not great enough to do any damage. Similarly, we decrease the resistance of a conductor by choosing a metal of low resistance per mil foot and making the conductor of large cross section, so that the temperature rise is not great enough to injure the insulation.

The National Board of Fire Underwriters has issued a table for the safe carrying capacity of copper wire of the sizes usual in house wiring. If a greater current than that indicated is carried by any wire, the insulation is heated, and is likely to melt or take fire. If this current is greatly exceeded, the copper itself is likely to be fused.

Example 12. It is desired to install a conductor to carry 40 amperes. What size copper wire should be used?

From the table, No. 6, rubber-insulated wire will carry 46 amperes, and is the size to be used.

If weatherproof wire can be used, No. 8 will do.

Prob. 98. What size rubber-covered wire should be used when it is necessary to carry 15 amperes?

Prob. 99. What would be the voltage drop in 200 ft. of the wire in Prob. 91, when carrying 15 amperes?

47. Relation of Voltage to Watts Lost in the Line. Let us assume that we wish to use eight 110-volt lamps, each taking $\frac{1}{2}$ amp., as in Fig. 90. The lamps are 2000 ft. from the generator and No. 7 wire is used, which makes about one ohm per wire.

The eight lamps taking $\frac{1}{2}$ amp. each, would take 4 amp. altogether.

To transmit 4 amp. over a 1-ohm wire requires 4 volts. There are two 1-ohm wires, so 8 volts would be required to force the current through the line out to the lamps and back again through the return line.

The power consumed in the line, then, equals

volts (used in line) × amperes (through line).
Watts = 8 × 4 = 32 watts used in line.

The watts used by the lamps equal

volts (across lamps) × amperes (through lamps)
= 110 × 4 = 440 watts used in the lamps.

Thus, in order to get the 440 watts to the lamps we have wasted 32 watts in the line.

Suppose that we now arrange these same lamps as in Fig. 91. By placing two in series in each case, each lamp

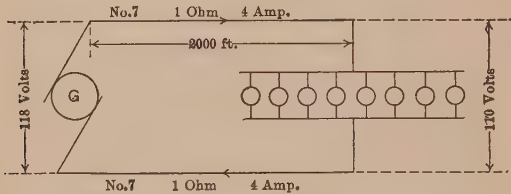


FIG. 90. Two-wire system. The two line wires each carry 8 times the current of 1 lamp.

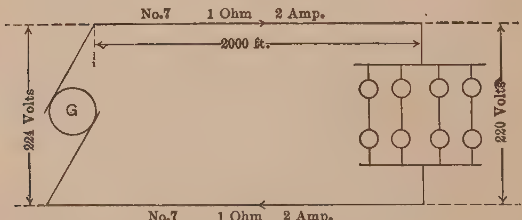


FIG. 91. Two-wire system. The two line wires each carry 4 times the current of each lamp.

can get its $\frac{1}{2}$ amp., and by making the voltage across the two lamps 220 volts, each lamp has 110 volts pressure.

So we really have but 4 parallel circuits each carrying $\frac{1}{2}$ amp. Thus the 4 circuits carry

$$4 \times \tfrac{1}{2} = 2 \text{ amp.}$$

The line, then, has to carry only 2 amp. and being the same wire as in Fig. 90 has a total resistance of 2 ohms.

The voltage required to send 2 amp. through 2 ohms is 4 volts. Thus the voltage drop in the line is 4 volts. The power lost in the line wires equals

volts (lost in line) × amperes (through line),

or

$$4 \times 2 = 8 \text{ watts.}$$

Power consumed by the lamps equals

volts (across lamps) × amperes (through lamps),

or

$$220 \times 2 = 440 \text{ watts.}$$

Thus we have transmitted the same power to the same lamps at 220 volts with only 8 watts loss against the 32 watts loss where 110 volts were used.

Note that doubling the voltage makes the line loss one-quarter as great. Thus, if we are to transmit at 220 volts, we can make use of the great advantage gained over 110 volts in either of two ways.

(1) We may use the same line wires as we would for 110 volts, and save operating expenses by taking advantage of the small line loss. The first cost of the outfit would be the same as the 110-volt transmission.

(2) Or we might wish to lessen the first cost of the outfit and allow operating expenses to be the same as for the 110-volt transmission. We would be enabled to do this by using a smaller copper wire. In fact, we might use wire having only one-quarter the area and still have the same line loss as in a 110-volt line transmitting the same power.

Thus, making use of this second advantage, we might use

a No. 13 instead of a No. 7 wire. The line **resistance** would then become 4 ohms per wire or a total of 8 ohms for the line.

It would require 8 × 2, or 16 volts to send the 2 amp. of Fig. 91 through this line.

The line loss would then become

$$16\ (\text{volts}) \times 2\ (\text{amp.}) = 32\ \text{watts},$$

which is the same as in the 110-volt line of Fig. 90, which used 4 times as large a wire.

So we could use a No. 13 wire which has only one-quarter the area of a No. 7, thus weighs only one-quarter as much, and costs only about one-quarter as much. Since the big item in the erection of a line is the cost of the wire, we can see that the cost of the line by using the smaller wire is only about one-quarter the cost of a line of the larger wire.

It is clear, then, that in transmitting at 220 volts, a great saving can be made either in operating expenses or in the first cost of installation.

48. Three-Wire System. This great saving of power or copper in the line by merely doubling the voltage has led to the wide establishment of 220-volt circuits. But lamps of about 110-volt rating are the most common type of incandescent lamp because they are the cheapest and most durable, and if they are to be used on a 220-volt circuit, they must be put two in series. This would compel a customer always to burn at least two lamps at once. If he needed three lamps, he would have to use four, two parallel sets of two in series.

To avoid this bad feature and still retain the advantage of transmitting at 220 volts, a third wire, called a **neutral**, has been added to the arrangement in Fig. 91, which produces the **three-wire system**, as shown in Fig. 92.

This neutral wire is usually the same size as each of the other two. So if we allow the same watts lost in the line,

the total amount of copper is a little greater than $\frac{1}{4}$ that of the two-wire system of Fig. 90. In fact, there is just $\frac{3}{8}$ as much copper in the three-wire system.

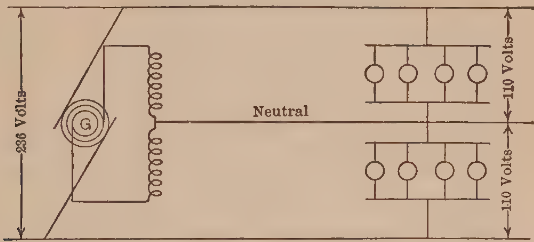


FIG. 92. Three-wire system. Each outside wire carries 4 times the current of each lamp. The neutral carries no current in this case.

The generator also has to have a special device to which this third wire is attached. It is much simpler, however, to consider the generator as divided into two 110-volt generators in series as in Fig. 93, with the neutral coming to the junction of the two.

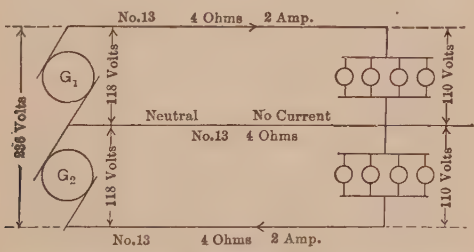


FIG. 93. Three-wire system; balanced. Neutral carries no current.

49. Balanced and Unbalanced Three-Wire System. When there are the same number of lamps burning on each side of the neutral, as in Fig. 93, the neutral carries no current, and the system is said to be **balanced**. It is only when the system is **unbalanced** that the neutral is of use

and carries current, as in Fig. 94. The system may be said to be unbalanced, then, when the appliances on one side of the neutral are carrying more current than those on the other side, thus compelling the neutral to carry the surplus. Thus, if four $\frac{1}{2}$-amp. lamps were turned on, as in Fig. 94, on

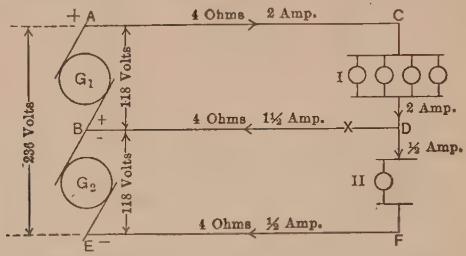


FIG. 94. Three-wire system; unbalanced. Neutral carries some current.

the (+) side of the neutral, and only one on the other side, the neutral would have to carry $1\frac{1}{2}$ amp. back to the generator G_1 which is supplying the greater part of the power. If, however, the four $\frac{1}{2}$-amp. lamps had been turned on, as

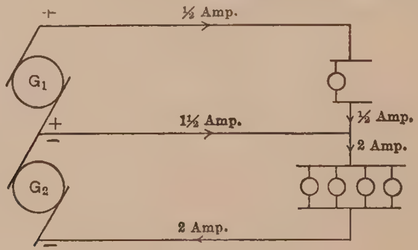


FIG. 95. Three-wire system; unbalanced. Neutral carries some current.

in Fig. 95, on the (−) side of the neutral, then since the (+) side is only supplying $\frac{1}{2}$ amp., the neutral must carry $1\frac{1}{2}$ amp. from the generator out to the lamps. G_2 is now supplying most of the power.

50. Voltage Distribution in Three-Wire System. In using the three-wire system, every effort is made to keep it balanced. In this case, the voltage, current and power distribution differ in no respect from that of a two-wire system, with lamps, or other electrical appliances, paired off, two in series, as in Fig. 91.

Of course on a large system any slight deviation from a balance makes no noticeable difference, but it is instructive to see what happens to the voltage distribution in a system unbalanced as much as that of Fig. 94.

The voltage across Group I is very easy to find.

To force 2 amp. through the line out to the lamps over a 4-ohm wire requires

$$2 \times 4 = 8 \text{ volts.}$$

To force $1\frac{1}{2}$ amp. through the return line to the generator over a 4-ohm wire (the neutral) requires

$$\begin{aligned} 1\tfrac{1}{2} \times 4 &= 6 \text{ volts.} \\ \text{Line drop} &= 6 + 8 = 14 \text{ volts.} \\ \text{Voltage across Group I} &= \text{voltage of } G_1 - (\text{line drop}) \\ &= 118 - 14 = 104 \text{ volts.} \\ \text{Voltage across Group I} &= 104 \text{ volts.} \end{aligned}$$

The voltage across Group II is a little more difficult to compute. The easiest way is to draw a "voltage diagram," as in Fig. 96 and 97. Fig. 96 represents the voltage diagram of the circuit for Group I.

Let the vertical line AB represent the 118 volts of the generator. Then draw the line wire AC sloping in the direction in which the current flows. Since the voltage drops 8 volts along the top wire, the line AC falls 8 from the level of A. In the same way the line DB slopes in the direction in which the current flows and falls 6 from the

level of D, representing the 6 volts lost in the neutral wire. The rest of the vertical distance, from the level of A to the level of B, is the voltage across the points C and D, where the lamps of Group I are located. This is 104 volts, which agrees with the result found by computation.

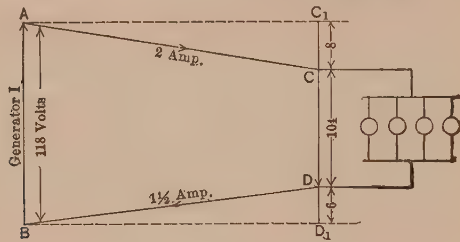


FIG. 96. Voltage diagram for upper part of Fig. 94.

Another way of stating it is that the distance between the horizontal lines is the voltage of the generator. Thus the line C_1D_1 would represent 118 volts. The line CD

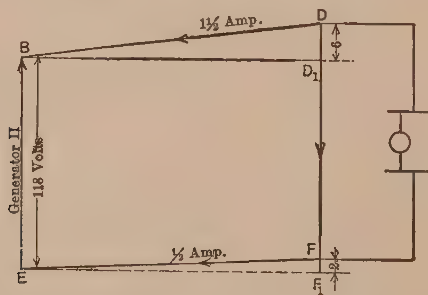


FIG. 97. Voltage diagram for lower part of Fig. 94.

is 14 shorter than C_1D_1 and therefore represents 104 volts, which is the voltage across the lamps, because they are across the points C and D.

If, now, we should consider the circuit of Group II in the same way we would draw Fig. 97. The vertical line BE

represents the voltage across G_2. BD is the neutral sloping toward the generator as drawn in Fig. 96, representing a fall of 6 volts toward the generator as a current is flowing in this direction. Line FE represents the wire EF in which a current of $\frac{1}{2}$ amp. is flowing to generator II. Therefore the line FE slopes toward the generator. Since the wire FE has a resistance of 4 ohms, it requires $\frac{1}{2} \times 4$, or 2 volts to force the $\frac{1}{2}$ amp. through it. Therefore the line FE falls 2 points from the level of F. Group II is connected to the line at points D and F, thus DF must represent the voltage across Group II. The distance between the horizontals is always the same as the voltage of the generator. The line D_1F_1, therefore, represents 118 volts. But the line DF, which represents voltage across Group II, is 2 shorter than D_1F_1 at one end, but 6 longer at the other; thus it must be in all, 4 longer. It therefore represents $118 + 4$ volts, or 122 volts. Since Group II is connected in at points D and F, it must have 122 volts across it. Thus the voltage across Group II is 122 volts.

The voltage across Group I was found to be only 104 volts.

The lamps of both groups were made to run on 110 volts as in Fig. 93, and would probably be ruined by 122 volts. We can say, then, that the result of extreme unbalancing is to so greatly disturb the voltage distribution, that appliances built for special voltages would not operate satisfactorily on the system.

Prob. 100. If there were 8 lamps in Group I and 2 lamps in Group II, Fig. 94, each taking $\frac{1}{2}$ amp., other things remaining unchanged, what would the voltage across each group become?

Prob. 101. What is the voltage distribution in Fig. 95, if the wires all have a resistance of $1\frac{1}{2}$ ohms? The generators maintain 115 volts each and each lamp takes 0.45 amp.?

51. Broken Neutral in a Three-Wire System. One other danger in a three-wire system is the chance that the neutral may become broken at the same time that the load is unbalanced. This is not at all a common occurrence, but it is interesting to see what happens when it does take place.

Consider the neutral in Fig. 94 broken at (x). We should then have a series circuit as in Fig. 98.

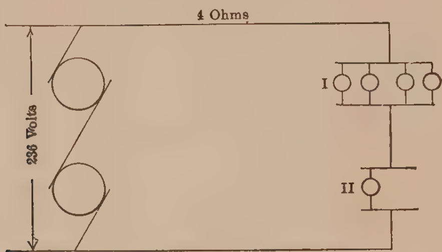


FIG. 98. Effect of broken neutral in the three-wire system of Fig. 94.

In order to get at the approximate value of the current that would flow, we will assume that the resistance of each lamp remains about 220 ohms, as it probably would.

Combined resistance of Group I	$= \frac{1}{4}$ of 220 =	55 ohms.
" " " Group II	=	220 "
" " " line	$= 4 + 4 =$	8 "
Total resistance	=	283 ohms.

$$\text{Total current} = \frac{\text{(total) voltage}}{\text{(total) resistance}} = \frac{236}{283} = 0.834 \text{ amp.}$$

Voltage across Group I.

Volts (across lamps) =

amp. (through lamps) $\times$ ohms (of lamps)

$= 0.834 \times 55$

$= 45.8$ volts.

Voltage across Group II.

Volts (across lamps) =

amp. (through lamps) $\times$ ohms (of lamps)

$$= 0.834 \times 220$$

$$= 183.5 \text{ volts.}$$

Thus lamps in Group I would not glow, while lamps in Group II would flash, all lamps being made for 110 volts.

Prob. 102. Find the distribution of voltage if the neutral in Prob. 100 broke.

Prob. 103. Find the voltage distribution if the neutral in Prob. 101 broke.

Prob. 104. Find the voltage distribution if the neutral in Fig. 93 broke.

SUMMARY OF CHAPTER V.

Wire is usually made of copper on account of its low resistance.

The resistance of one foot of any size wire being known, the resistance of any length is found by multiplying by the length in feet.

The resistance of one foot of wire $\frac{1}{1000}$ inch in diameter being known, the resistance of one foot of wire of any diameter can be found by dividing by the square of the diameter in thousandths of an inch.

A MIL is $\frac{1}{1000}$ inch.

A CIRCULAR MIL is the area of a circle one mil in diameter.

The area of any circle in circular mils equals the square of the diameter in mils.

A UNIT WIRE is called a mil-foot, and is a round wire one foot long and one mil in diameter.

The resistance of a mil-foot of copper wire is 10.4 ohms.

The resistance of a round copper wire equals

$$\frac{10.4 \text{ (resistance of mil-ft.)} \times \text{length in feet}}{\text{circular mil area}}.$$

The resistance of standard sizes of copper wire may be found from wire tables.

Wire is often stranded for greater flexibility. The gauge number of stranded wire depends upon the total circular mil area of all the strands and is equivalent to a solid wire of the same area.

The resistance of a mil-ft. of aluminum wire is 18.7 ohms.

The resistance of a mil-ft. of iron wire varies from 60 to 90 ohms.

The resistance of a mil-ft. of alloys, such as manganin, German silver, etc., may be as high as 600 ohms.

For interior wiring, the Underwriters will not insure a house where the wires carry more than the current indicated in the table, "Safe Carrying Capacity of Copper Wires." This is because of the heating effect of the current.

The same amount of power can be transmitted over the same wires at $\frac{1}{4}$ the line loss in watts if 220 volts are used instead of 110 volts.

The same amount of power can be transmitted at the same loss in watts over wires of $\frac{1}{4}$ the weight (or area) if 220 instead of 110 volts be used.

To secure either of these advantages and still not prevent the use of 110-volt appliances, the THREE-WIRE system has been invented.

The NEUTRAL carries current only in case one line wire is carrying more current than the other. This is called an UNBALANCED CIRCUIT and results in an uneven distribution of the voltage. A broken neutral at the same time may ruin appliances attached to the line.

PROBLEMS ON CHAPTER V

Prob. 105. How many 110-volt lamps, each taking $\frac{1}{2}$ amp., can be put on a circuit where the watts are not to exceed 660?

Prob. 106. What size wire must be used for the conductor in Prob. 105?

Prob. 107. What will be the voltage drop along 300 ft. of the wire in Prob. 106, when it is loaded as in Prob. 105?

Prob. 108. Seven No. 19 copper wires are stranded into a cable. To what size (B. & S.) gauge is the cable equivalent?

Prob. 109. How many strands of No. 15 wire should be in a cable which is equivalent to a No. 6 solid wire?

Prob. 110. How many strands of No. 19 wire will it take to make a cable equivalent to a No. 5 solid wire?

Prob. 111. What is the diameter of a solid wire having 60,000 cir. mils area?

Prob. 112. How many No. 18 strands will it take to make a cable equivalent to the solid wire of Prob. 111?

Prob. 113. What would be the carrying capacity of the wire in Prob. 111?

Prob. 114. What is the safe carrying capacity of the cable in Prob. 108?

Prob. 115. What size aluminum wire is equivalent in resistance to No. 6 copper wire?

Prob. 116. What would be the safe carrying capacity of the aluminum wire in Prob. 115?

Prob. 117. Assume that each lamp in Fig. 99 takes 2 amperes, and that the resistance of the lamps remains constant. The brush potential of each generator is 112 volts. Find·

(*a*) The line drop in each section.
(*b*) The voltage across each set of lamps.
(*c*) The power delivered by G_1 and by G_2.

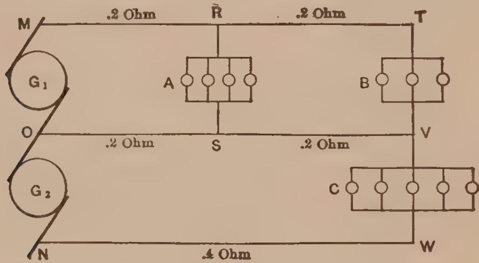


FIG. 99.

Prob. 118. If a break should occur in the neutral between O and S, what would be the values of (*a*), (*b*) and (*c*), Prob. 117?

Prob. 119. If a break should occur in the neutral between S and V, what would be the values of (*a*), (*b*) and (*c*), Prob. 117?

Prob. 120. It is desired to deliver 100 h. p. at a pressure of 550 volts to a point 2 miles from the generator. The watts lost in the line are not to exceed 7% of the watts delivered. What size copper wire should be used?

Prob. 121. What size aluminum wire should be used in Prob. 120?

Prob. 122. What size copper wire should be used to convey current to a group of 200 lamps, each rated at 110 volts, 40 watts? The generator maintains a pressure of 118 volts and is 800 ft. from the lamps.

CHAPTER VI

GENERATORS AND MOTORS

It should be said in the first place that any electric motor may be run as a generator, or vice versa. If electric power is generated outside the machine and brought to it, and if this power puts the machine in motion and thus runs other machinery, the machine is called a **motor**. If,

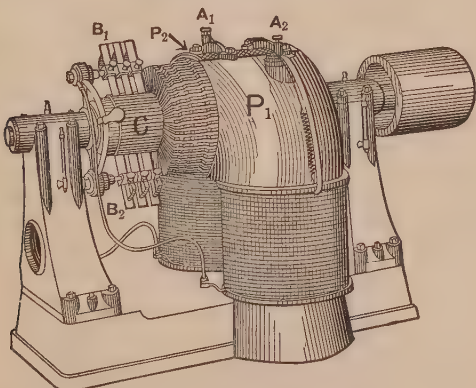


Fig. 100. Simple old-type two-pole generator.

on the other hand, the machine derives its mechanical power from some source outside of itself, and delivers electric power, it is called a **generator**. The term **dynamo** includes both generator and motor.

52. Voltage Generated in Armature Wires. Fig. 100 represents the simplest form of two-pole direct-current generator or motor. As a generator, the power is delivered by

the commutator C to the brushes B_1 and B_2 from which it is brought by flexible cables to the terminals A_1 and A_2.

Right here it is well to state that the electric power is not generated by the brushes rubbing on the commutator. The voltage is gene ated by the wires wound on the revolv-

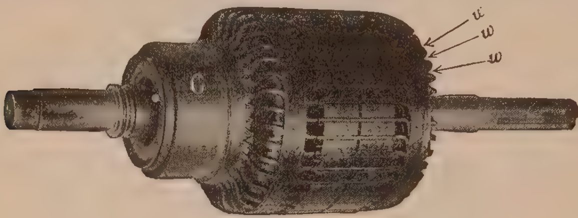


Fig. 101. Westinghouse armature.

ing armature moving near strong magnets. Fig. 101 shows such an armature taken out of the frame. The wires (w) running in slots lengthwise along it, are joined to the commutator C. As these wires move under the strong magnets, a voltage is set up, which tends to send an

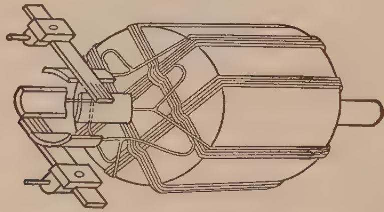


Fig. 102. Simple diagram of drum-wound armature with commutator and brushes.

electric current through the wire. If an electric circuit is put across the brushes, this current will flow from the (+) brush through the outside circuit to the (−) brush, into the commutator, along the wires in the armature and back to the (+) brush. Fig. 102 shows a simple diagram

of such an armature. It is necessary to keep well in mind the fact that a voltage is set up in any electrical conductor which is moving across a strong magnet. If we take a simple bar magnet and move a wire quickly across the face of it, as in Fig. 103, there will be a voltage set up across the terminals

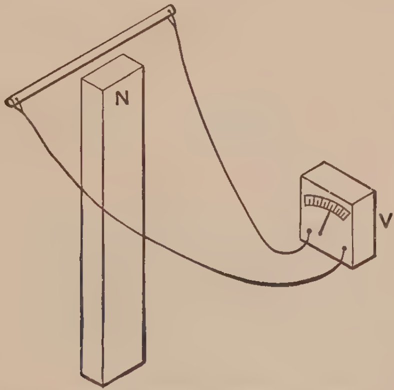


FIG. 103. When the wire is moved across the face of the magnet N, a voltage is set up which is indicated on the voltmeter V.

of the wire which will be indicated on the voltmeter. If we now move the wire in the opposite direction the voltmeter will indicate in the opposite direction, showing that it makes a difference in what direction the wire is moved. It is the moving of all the wires wound on the armature close to the magnetic poles of the machine which sets up the voltage. The amount of voltage that is set up depends upon the speed of the wire and the strength of the magnet. Thus, if we move a wire twice as quickly across the face of a magnet we obtain twice the voltage, or if we move it at the same speed across the face of a magnet twice as strong, we obtain twice the voltage. The high voltage of a generator is obtained by moving many wires in series very rapidly across the faces of very strong magnets.

Of course, the magnets of a machine are not bar magnets, but **electromagnets** of different shapes. They have exactly the same effect, however, as is seen from the following.

53. Magnets. If we place a glass plate over a bar magnet and scatter iron filings on it, the filings will arrange themselves in lines, called **magnetic lines of force,** as in

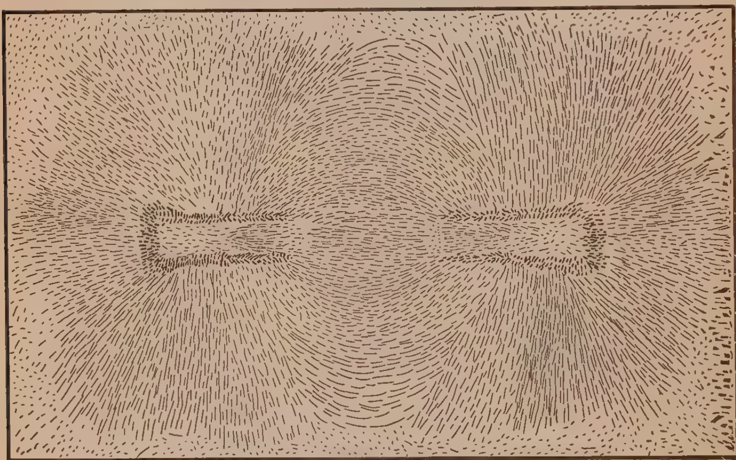


Fig. 104. Magnetic lines shown by iron filings.

Fig. 104. Note how these lines all seem to come out of one end of the magnet and go into the other end. As both ends look exactly alike, we cannot tell from which end the lines are coming out and which they are going into, except by the use of a compass. If we place a compass near one end of a magnet and it points away from that end, we say that end is the **north** pole of the magnet, and that the lines coming out of this north pole push the compass around so that it points away from the north pole. Similarly, the lines going into the **south** pole pull the compass

around so that it points toward the south pole. Thus we say that:

> **The north pole of any magnet is the place where the magnetic lines come out, and the south pole is any place where the lines enter the magnet.**

The lines, then, run through the magnet from the south pole to the north pole, out of the north pole, through the air, and enter the south pole again, making a complete loop. The place where the lines are in the air is called the **magnetic field.** Fig. 105 is a diagram of the magnetic paths of a bar magnet.

FIG. 105. Diagram of magnetic lines of force in and about a bar magnet.

54. Magnetic Field of a Motor. The magnetic field of the two-pole motor in Fig. 100 is merely the field of a bar magnet bent into a horse shoe as in Fig. 106. Note that here, too, the lines come out of the north pole and enter the south pole, go through the yoke and back again to the north pole. The armature revolves in the field between the north and south poles, and the wires on it cut the magnetic lines of the field and produce a voltage across the commutator, where it is transmitted to the brushes. Fig. 107 shows the field of a four-pole motor. Note that the lines come out of a north pole and go into a south pole, and that north poles and south poles alternate around the frame.

Prob. 1. Draw a 6-pole motor frame showing the complete paths of the magnetic lines.

Prob. 2. Draw an 8-pole generator frame showing the complete paths of magnetic force lines.

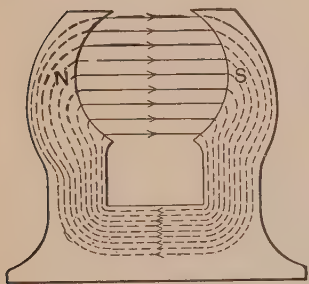


Fig. 106. Diagram of the magnetic lines in a two-pole generator.

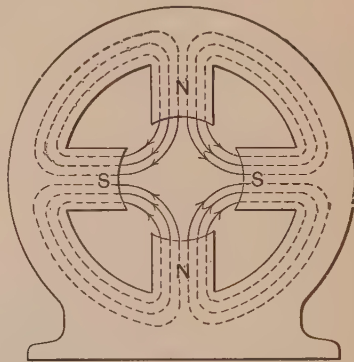


Fig. 107. Magnetic lines in a four-pole generator.

55. Electromagnets. Field Coils. We have seen the important part that a magnetic field plays in a dynamo; now we will consider how this field is created.

We are all acquainted with the fact that when once a piece of hard steel has become magnetized, it remains a magnet. A piece of soft steel or iron, however, loses nearly all its magnetism as soon as the magnetizing force is removed. Now the pole pieces of dynamos are all made of soft steel or iron, and it is necessary to keep a magnetizing force present all the time.

It will be noted that around the pole pieces P_1 and P_2 of Fig. 100, there are wound coils of wire. These coils supply the magnetizing force to the pole pieces. For when an electric current is sent through these coils a magnetic field is created, its direction depending upon the

direction of the electric current in the coils. The rule for this direction is illustrated in Fig. 108 and 109, and Fig. 110 and 111.

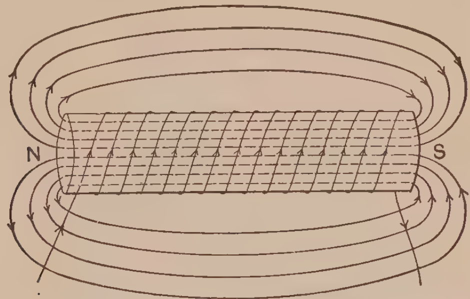


FIG. 108. Magnetic field of a coil carrying an electric current.

Grasp the coil with the right hand so that the **fingers** point in the direction of the electric **current**, and the **thumb** points in the direction of the **north pole.**

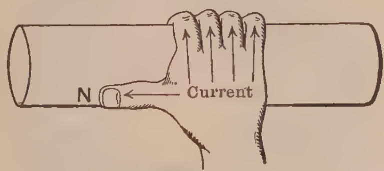


FIG. 109. Fingers point in the direction of the electric current; thumb points in the direction of the north pole of the coil.

Note that the field of such an electromagnet is exactly like the field of a bar magnet. If we want a stronger magnetic field, we can either send a larger current through the turns of wire around the bar, or keep the same current flowing, but wind on more "turns." The product of the **amperes** times the **turns** is called the **ampere-turns,** and determines the magnetizing force of the coil. If a weak

magnet is required, only a few ampere-turns are used and no iron core is inserted. For a strong magnet, a large number of ampere-turns to the inch are wound on an annealed steel or iron core. To form a permanent magnet, we have merely to insert a bar of glass-hard steel and turn on the

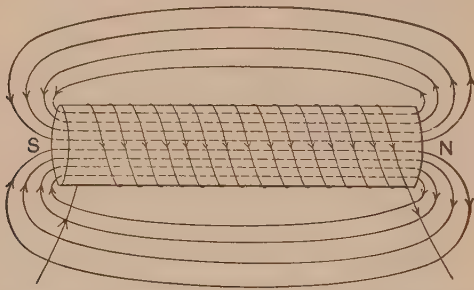


FIG. 110. Current in the coil is reversed, and the magnetic lines are reversed. Compare Fig. 108.

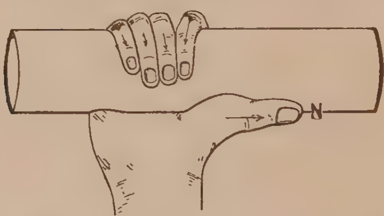


FIG. 111. Fingers point in direction of the electric current; thumb points toward the north pole.

current for a few seconds. When the current is turned off and the bar taken out, it will be found to retain a large share of its magnetism for a long time.

In order to produce a field as in Fig. 106, which is the field for the machine of Fig. 100, we merely have to wind coils around the pole pieces and send a current through the coils in the proper direction, as in Fig. 112.

Fig. 113 is an illustration of such a four-pole machine. Fig. 114 shows one of the field coils on one of the pole pieces ready to be adjusted to the frame.

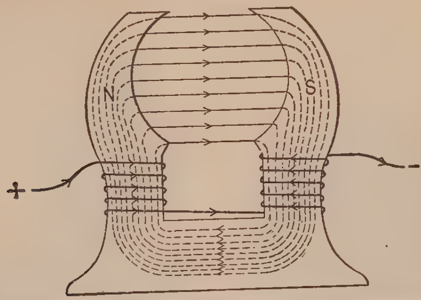


FIG. 112. The current in the coils produces the magnetic field.

FIG. 113. A Westinghouse four-pole generator frame with pole pieces and field coils.

Prob. 3. Draw the magnetic field and field coils with current for a 6-pole motor.

Prob. 4. Put field coils on the generator of Prob. 2 with field currents to produce poles as marked.

An illustration of the field of a modern two-pole dynamo is shown in Fig. 115. The path of the magnetic lines is shown in Fig. 116.

Fig. 114. Pole piece and field coil.

Fig. 115. Westinghouse two-pole motor or generator.

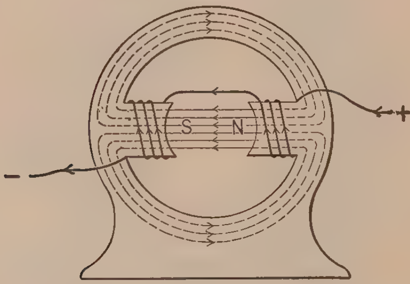


Fig. 116. Path of magnetic lines in modern two-pole generator of Fig. 115.

In setting up a motor or generator it is necessary then to note the polarity (whether a pole is north or south) and to cause the current to flow in such a direction through the field coils as to make the poles alternately north and south.

56. Fields Separately or Self-Excited. Direct-current generators are classified as to the source from which the field coils receive their electric current. They are:

Separately excited, when the field current comes from some outside source, as storage cells, exciter generators, etc.

Self-excited, when the field current is drawn from the armature of the machine itself.

57. Separately Excited Field. Self-excited machines sometimes change their polarity when not in use. It is customary, therefore, to use a separately excited generator whenever it is desired that the current shall never change its direction. This point is of greatest importance in electroplating.

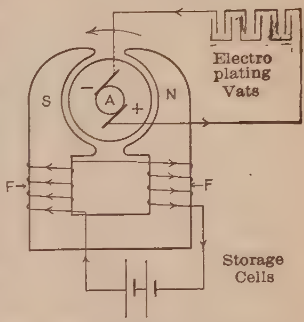


FIG. 117. Separately excited generator, supplying current to electroplating vats.

Fig. 117 represents the connections for a separately excited generator supplying current to a set of electroplating vats. The fields are excited from a storage battery, thus insuring a permanent polarity. Fig. 118 shows the standard way of representing a separately excited generator, connected to electroplating vats V.

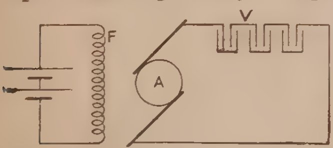


FIG. 118. Conventional diagram for Fig. 117.

58. Self-excited Field. Self-excited generators are divided into three classes.

Shunt. Only a small part of the current delivered by the armature goes through the field. This field current is said to be **shunted** around the main line current.

Series. All the current delivered by the armature goes through the fields before it goes out of the machine.

Compound. Two coils are supplied to each pole. One, called the shunt coil, takes a **shunted** current; the other, called the series coil, takes the full or **series** current. This is by far the most common type of generator.

Motor fields are classified in the same way. If the same current supplied to the motor goes through both the armature and field coils, the motor is called a **series motor.**

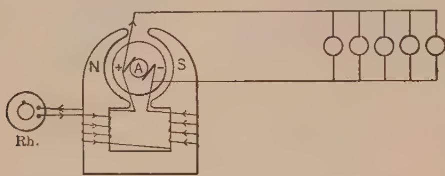


FIG. 119. Shunt generator, supplying incandescent lamps with current.

If the current is divided, part going through each, it is called a **shunt motor.** A combination of the two is called a **compound motor.** Except in trolley cars and motors for other traction work, the shunt motor is the most common.

59. Shunt Generator. When the fields are excited by a current shunted around the main circuit, as in Fig. 119 and 120, many turns of fine copper wire are used. In this case it is not desirable to have a large current going through the coils, because every bit thus used is really stolen from current available for the outside circuit. The resistance of the coils is therefore high. The necessary

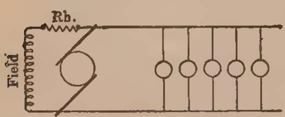


FIG. 120. Conventional diagram of Fig. 119.

number of ampere-turns are obtained by the large number of turns which make up for the small current.

60. Building Up of Shunt Field. Even when no current flows through the field coils of a machine there is always a small amount of magnetism in the field. So when we start up a shunt generator, the armature conductors are revolving in a very weak field. But as the wires of the armature cut through this weak field, a small voltage is produced across the brushes. Now, since the field coils are connected directly across the brushes (see Fig. 119 and 120), a small current will be sent through these windings. This will slightly increase the strength of the magnetic field. As the armature now revolves in this increased field, the voltage across the brushes will be raised a little, which in turn will send a larger current through the field coils, which still further increases the magnetic field, raises the voltage, and increases the field current. This is called the **building up** process of the field, and it continues until the fields have enough magnetism to produce full voltage, the value of which depends upon the speed of the armature and the resistance of the field circuit. This process usually takes from 10 to 30 seconds. After the voltage has become constant, it can be controlled further and set to any definite value within the limits of the machine, by means of an adjustable resistance in series with the field. If the voltage is too high, it can be lowered by increasing the resistance, thus lowering the field current, which weakens the magnetic field and therefore lowers the voltage produced in the armature conductors. We can also raise the voltage by increasing the speed of the armature, or lower the voltage by decreasing the speed of the armature. Then the voltage across the brushes remains constant and is ready to deliver current to the outside line.

61. Connections of a Shunt Generator. In connecting up a shunt generator, first trace back the leads from the terminals as shown in Fig. 121. Two of the leads will be

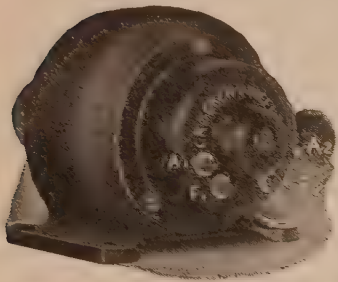


FIG. 121. Simple shunt generator.

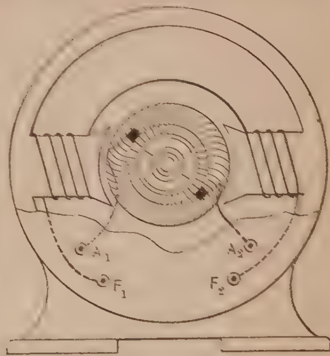


FIG. 122. Connections to terminals in generator of Fig. 121.

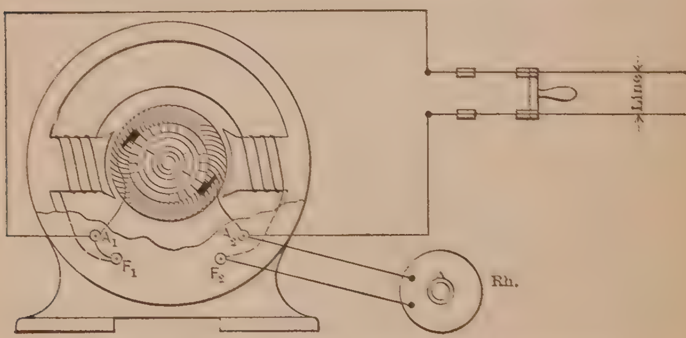


FIG. 123. Generator of Fig. 121, connected for running.

found to go to the fields as the leads from the terminals F_1 and F_2, Fig. 122. Two will be found to be connected with the brushes, as those from terminals A_1 and A_2.

Since the current in the field must come from the brushes,

it is necessary to connect F_1 to A_1 and F_2 to A_2 through an adjustable resistance *Rh*, Fig. 123.

The line is then connected through a switch and fuses to the terminals A_1 and A_2.

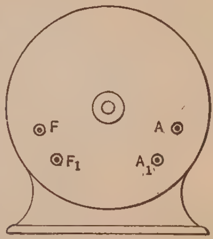


Fig. 124.

Note. If the generator will not build up, reverse the field connections; that is, connect F_1 to A_2 and F_2 to A_1. If it still will not build up, excite the field from some outside source. Dry cells will often start the building-up process. If this does not work, test out the polarity and proceed as per directions in Chapter VII.

Prob. 5. The terminals of a shunt machine, when traced back, were found to be connected as marked in Fig. 124 (A-A_1 to arm and F-F_1 to field). Show connections through a field rheostat for use as a generator.

62. Compound Generators. Shunt generators have one fault; as soon as any current is allowed to flow from a machine into the line, the voltage falls a little and it continues to fall, as more and more current is taken. To counteract this tendency of the voltage to fall as the load rises, the load current is led through another set of coils, called the series coils, before it is allowed to go into the line. Now the more current the line takes, the more current the series coils have, and the more strongly magnetized the fields become. This keeps the voltage the same, no matter what current (within the limits of the machine) is taken by the line. Such a generator is called a flat-compound generator. Of course most of the magnetic lines in the field come from the current in the shunt coils; the series coils have just enough ampere-turns to increase this magnetism sufficiently to make up for the tendency of a shunt generator to lower slightly in voltage as the load increases.

In Fig. 125 the connections of a compound generator are shown, coils *C* being the series coils, and coils *B*, the shunt. Note, in Fig. 126 and 127, the two ways of connecting the shunt field of a compound generator.

Series generators are very rarely used except in series arc lighting systems.

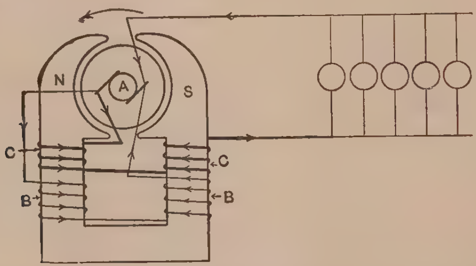


Fig. 125. A compound generator feeding incandescent lamps.

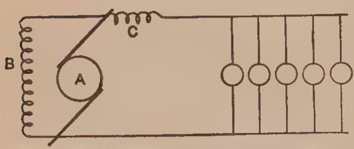


Fig. 126. Diagram of a short-shunt compound generator.

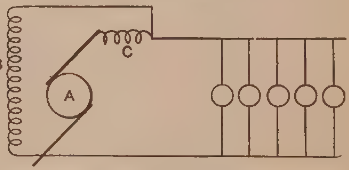


Fig. 127. Diagram of a long-shunt compound generator.

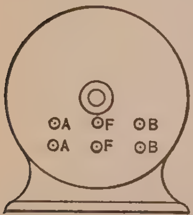


Fig. 128. Compound generator.

Prob. 6. In Fig. 128, terminals *A-A* are connected to the armature, *F-F* to the shunt field coils, *B-B* to the series field coils. Show connections for a long-shunt compound generator, with a rheostat in the shunt field.

Prob. 7. Connect the generator in Fig. 128 as a short-shunt generator, with a rheostat in the shunt field.

63. Commutating Poles. In between the main poles, most modern machines have smaller poles called **commutating poles.** See Fig. 128a.

These poles are not to generate power in the armature, but merely to keep the brushes from sparking on heavy loads or high speeds. The coils on the poles are always in series with the armature, so that their strength depends upon the armature current. Due chiefly to these poles, motors are now built which will reverse at full speed and not spark at the brushes.

FIG. 128a. Frame of a General Electric two-pole generator showing partial assembly. The two small pole pieces are the commutating poles.

The polarity of the commutating poles can be found as follows: Determine the polarity of the main poles and the direction of rotation of the armature. Then if you place your hand on one pole after another, going around the frame in the direction of rotation of the armature, any commutating pole will always have the same polarity as the main pole **following** it, if the machine is a generator; and as the main pole **behind** it, if the machine is a motor.

Note, in Fig. 129, that if we start with the north pole at the top and go around the frame clockwise (the direction in

which the armature is rotating), we come next to a south interpole, which is of the same polarity as the next main pole we come to, etc.

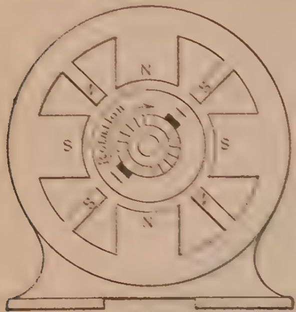


FIG. 129. Four-pole generator with commutating poles.

Prob. 7a. Draw the field coils on the main shunt poles and commutating poles in the generator, Fig. 129, showing the direction and source of current in each coil.

Prob. 8. Draw same as in Prob. 7a, making the armature rotate in the opposite direction.

64. Number of Brushes. A generator usually has the same number of sets of brushes as it has poles, not counting commutating poles. Note that the generator in Fig. 130 has six poles and six sets of brushes. Since a machine has but two terminals which are connected to the brushes, several of these sets of brushes must be joined together. Note, in Fig. 131, that every other brush is (+) and that all the (+) brushes are joined together in parallel and brought by leads to the (+) terminal. The remaining sets of brushes are (−) and are joined in parallel and lead to the (−) terminal.

Motors

Any machine which is used as a generator can be used as a motor if electric power is sent into the armature, instead of being taken from it. The current flowing in the armature conductors, acted upon by the magnetic field, causes the wire to move across the face of the magnetic pole as explained in the following paragraphs.

65. Field About a Straight Wire. When an electric current flows along a straight conductor, a circular magnetic field is formed around it as shown in Fig. 132.

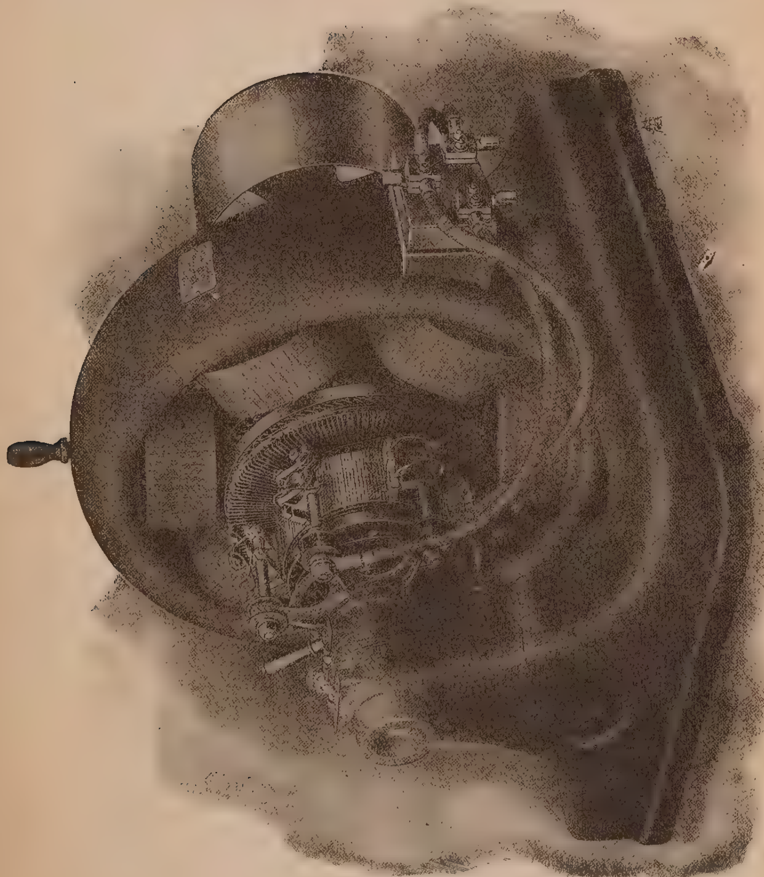


Fig. 130. Fort Wayne six-pole generator.

The direction of these magnetic whirls around the wire depends upon the direction of the electric current along the wire. By noting the above figure, it will be seen that if

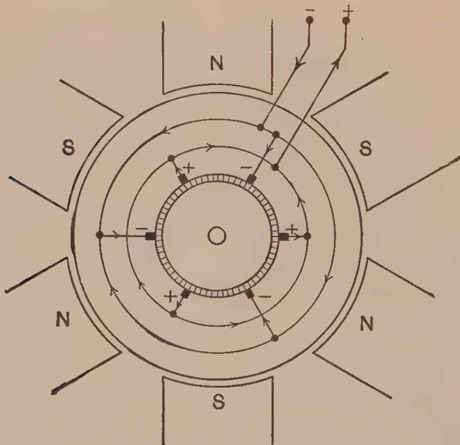


FIG. 131. Brush connection of the six-pole generator of FIG. 130.

we look along the wire in the direction of the current, the magnetic field whirls around the wire in the direction we would turn down a right-hand screw or nut. Notice in particular that these whirls are not **spirals** but are **circles.**

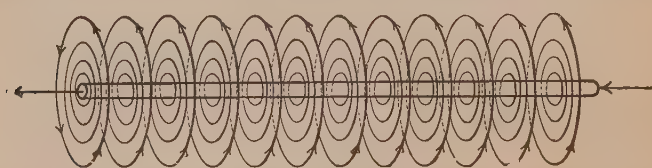


FIG. 132. The magnetic field about a straight wire carrying a current.

Fig. 133 shows a cross section of the wire and magnetic field and represents the way the field would appear if we looked at the end of the wire with the current going away

from us. In Fig. 134 the current is reversed. Notice that the field also is reversed in direction.

Fig. 135 and 136 show this circular field about a wire carrying a current taken by means of iron filings.

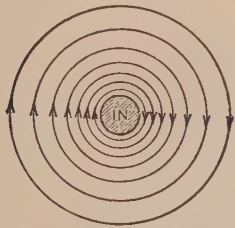


FIG. 133. Magnetic field about a straight wire: end view.

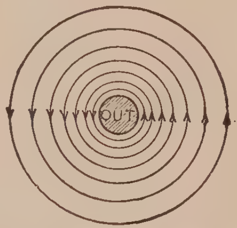


FIG. 134. Magnetic field about a straight wire: end view when the current is the reverse of that in Fig. 133.

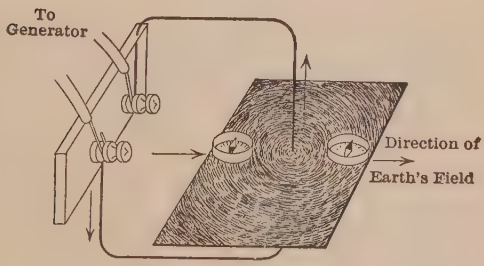


FIG. 135. The magnetic field about a wire shown by compasses and iron filings.

66. Reason for Rotation. In the case of a wire wound on an armature core of a motor, we have a straight wire carrying a current, placed in the magnetic field of the poles. There must then be present two magnetic fields; the circular field around the wire, and the almost parallel field of the poles. Fig. 137 shows the result obtained by means of iron filings. The wire carrying its current is placed in the

field between a north and a south pole. Note that the result is a field neither circular nor parallel, but that the lines seem to crowd together above the wire and are very much scattered below the wire.

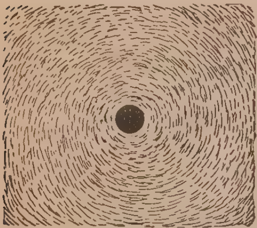


FIG. 136. Magnetic field about a wire, shown by iron filings.

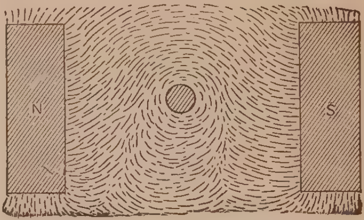


FIG. 137. The shape of the magnetic field is due to the current in the wire and the field between the two poles.

This crowding effect of the magnetic lines above the wire tends to force the wire down into the space less crowded. So whenever a wire is placed across a magnetic field and a current is sent through it, the wire is crowded one way or

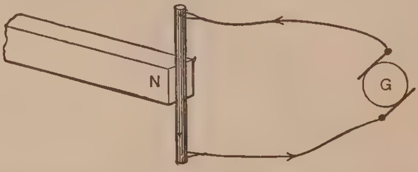


FIG. 138. When a current is sent through the wire, it tends to move sideways.

the other by the combined action of the circular magnetic field around the wire and the field in which the wire is placed.

This can be further illustrated as follows: If the copper wire in Fig. 138, having no current flowing through it, is

placed before the pole of a bar magnet, it will not tend to move in any direction, because magnetic lines have no action on copper. But if a current is sent through the copper wire, it will tend to move sideways. If the current is reversed, it will tend to move in the opposite direction.

The force with which the wire tends to move depends upon the strength of the magnet and the amount of current going through the wire. If twice the current is flowing through the wire, then there is twice the force tending to move it sideways across the face of the magnet. If the same current is sent through the wire, but a magnet twice as strong to the square inch end area is used, then the force is again twice as much.

The powerful forces exerted by motors are obtained by using many wires carrying large currents, placed near strong magnets.

It is just this action of the magnetic field of the motor on the currents in the wires of the armature that causes the armature to rotate. The wires are in the form of loops, so that the current flows in opposite directions when the wires are near opposite poles. Thus all the forces tend to pull the armature around in the same direction.

67. Voltmeters and Ammeters. Voltmeters and ammeters are really small motors and illustrate the practical application of this force existing between a parallel field and a wire carrying a current. The only difference is that the poles are permanent magnets, and the armature is not allowed to rotate, but turns against a spring.

Fig. 139 shows a cutaway view of the moving coil of a Weston ammeter.

Fig. 139a is a detailed drawing of this coil and Fig. 140 shows the action of the coil as a current is sent through it.

The coil *AB* is carefully set on jeweled bearings between the poles of a permanent aged magnet *N* and *S*. Watch-

springs W hold the coil in place, so that the pointer is held at zero on the scale, when no current is flowing through the

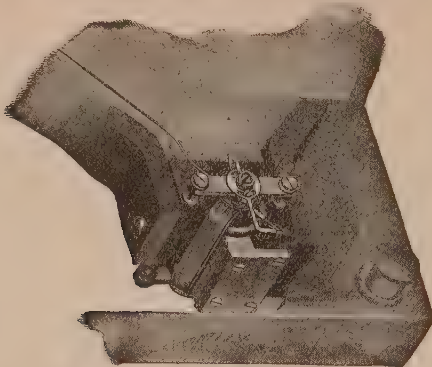


FIG. 139. Cutaway view of a Weston ammeter. The coil acts like the armature of a motor.

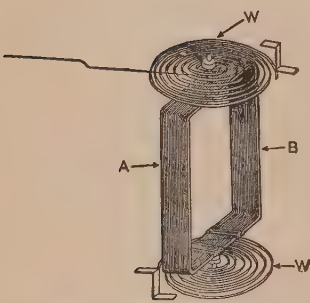


FIG. 139a. Diagram of coil in the Weston ammeter.

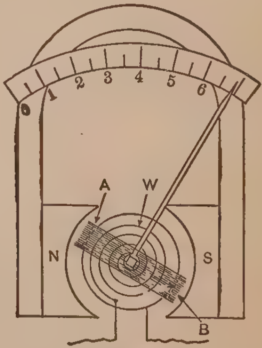


FIG. 140. Diagram showing motor action of coil in a Weston ammeter.

coil. Suppose a current is led into the moving coil so that it goes down along the side B and up the side A. On a top view, Fig. 140, the current would go in at B and

out at A. The clockwise circular field around B would strengthen the field of the permanent magnet NS, **above** the wires B and weaken it **below.** This would urge the side B **downward.** In the same way the counter clockwise field about A would strengthen the magnet's field below A and weaken it above. Thus A would be urged **upward.**

These two actions would cause the coil to turn against the tension of the springs W. The stronger the current flowing through the coil, the stronger the combination fields causing the coil to turn. The pointer would then indicate the current as it moved over a scale graduated in amperes. The instrument is thus an ammeter. As the current in any coil is proportional to the voltage across its terminals, the amount the coil turns must also be proportional to the voltage. The scale accordingly might be graduated to read volts. It would then be a voltmeter and would contain much greater resistance, as explained in Chapter I.

68. Starting Resistance. In starting a motor of any size it is not safe to throw the full line voltage across it at once. The armature has a very low resistance, so a large current would be forced through it and would burn it up. It is therefore necessary to put a box containing an adjustable resistance, called a **starting resistance,** in series with the armature in order to cut down this current. This box is always arranged so that as the motor gets up speed, the resistance can gradually be cut out until, finally, the full line voltage is across the motor.

The reason why the full voltage will not force enough current through the armature to injure it when **running,** but will burn it up if it is **not running,** is very simple.

When the armature is revolving, the wires wound on it are cutting through a strong magnetic field and thus must

be setting up a voltage in the armature, just as a generator does. Now this voltage is always in the direction opposite to the current which is causing the motor to run, and thus limits the flow of the current. It is called the "Back voltage," or "Counter Electromotive Force." Therefore the voltage, which at any time is forcing a current through a revolving armature, is not the voltage of the line, but "**the voltage of the line minus the back voltage in the armature.**" The current, then, still obeys Ohm's Law, which may be stated as follows:

$$\text{Current (through armature)} = \frac{\text{line volts} - \text{back volts}}{\text{resistance of armature}}.$$

Of course when the armature is standing still, there is no back voltage, so the line voltage is free to act, unless a starting resistance is put in series to cut down the current.

Example 1. The resistance of the armature of a 2-h.p. motor is 0.4 ohm. What current will it take if thrown directly across 110 volts when standing still?

$$\text{Amperes (through arm.)} = \frac{\text{volts (across arm.)}}{\text{ohms (of arm.)}}$$

$$= \frac{110}{0.4} = 275 \textbf{ amp.}$$

This current would quickly melt the copper in the armature of a 2-h.p. motor.

Example 2. When the motor in Example 1 is running at normal speed it has a back voltage of 103 volts. What current flows through the armature when running at normal speed with 110 volts across it?

$$\text{Amperes (through arm.)} = \frac{\text{line volts} - \text{back volts (across arm.)}}{\text{ohms (of arm.)}}$$

$$= \frac{110 - 103}{0.4} = \frac{7}{0.4} = 17.5 \text{ amp.}$$

Example 3. The normal current for motor in Example 1 is 18 amp. How much resistance must be used in the starting box so that the starting current shall not exceed $1\frac{1}{4}$ times the normal current?

$$\text{Starting current} = 1\tfrac{1}{4} \times 18 = 22.5 \text{ amp.}$$

$$\text{Resistance (of combination)} = \frac{\text{volts (of combination)}}{\text{amperes (of combination)}}$$

$$= \frac{110}{22.5} = 4.89 \text{ ohms.}$$

But the armature itself has 0.4 ohm. Thus the box must have

$$4.89 - 0.4 = 4.49 \text{ ohms.}$$

Fig. 141 is a simple diagram of the starting resistance used with a shunt motor. When the line switch is thrown and C is swung to the first point, it merely puts the shunt field

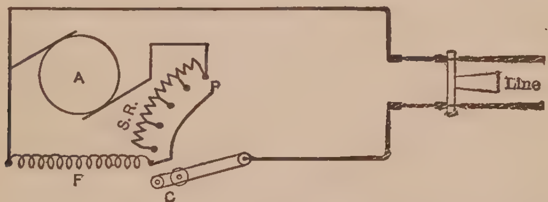


FIG. 141. Diagram of starting resistance for shunt motor.

F on to the circuit, thus building up the field immediately. Then when the arm C is swung to the next contact point, the starting resistance SR is put in series with the armature across the line. The resistance SR prevents too large a current from entering the armature. As soon as some speed is acquired by the armature (and therefore a back voltage), the arm C is swung to the next contact point, cutting out some of the resistance. As the motor gets up towards its full speed, the rest of the resistance SR is gradually cut out. Finally the armature is put directly across the line, by swinging the arm C to the point P.

Prob. 9. In Fig. 141 the starting resistance *SR* is 4.7 ohms; the armature has 0.8 ohm. What current does the armature take when starting on 112 volts?

Prob. 10. The field coils *F*, Fig. 141, have a resistance of 200 ohms. What current do the field coils take when on 112 volts?

Prob. 11. What current does the motor of Prob. 9 and 10 take when starting on 112 volts?

Prob. 12. The back voltage of the motor in Prob. 11, when running with all the starting resistance cut out, is 100 volts. What current does the motor then take?

Prob. 13. The armature resistance of a 4-h.p., 220-volt motor, is 1.5 ohms. Field resistance is 400 ohms. The motor takes, when running under full load, 4.5 amp. per h.p. What starting resistance is necessary in order that the starting current shall not exceed $1\frac{1}{4}$ times the full load current?

Prob. 14. What must be the back voltage of the motor in Prob. 13 when all the starting resistance is cut out?

69. Speed Control of Shunt Motors. The shunt motor has two excellent points:

(1) Nearly constant speed at all loads.

(2) Possibility of controlling the speed by field resistance and armature resistance.

To decrease the speed of a shunt motor, resistance may be inserted in the armature circuit. This, of course, very much cuts down the power of the motor and is an expensive method of control.

To increase the speed of a shunt motor, we have only to insert some resistance in series with the field coils. It may seem strange that the weaker the field, the faster the motor goes, but such is the case. In fact, if the current is all cut out from the field of a shunt motor, the speed of the armature becomes so great that it flies apart and wrecks the machine.

But motors are now made in which the field may be

weakened to a great extent and large changes in speed effected by means of an adjustable resistance in series with the field. Such a motor is called an "Adjustable Speed Motor" and invariably is fitted with commutating poles. Unless a motor is especially designed for the work, great care should be taken to increase the armature speed but very little above the rated value.

70. No-field Release. Starting Box. To prevent the destruction of a shunt motor by the accidental shutting off of the field current, a device called a "No-field Release" is applied to the connections. This is usually combined with the starting resistance and the two form the **starting box.**

The **"no-field" release** is merely a device for shutting off all the power from a motor as soon as the field current is broken. Thus the machine will stop rather than speed up and burst. Fig. 142 shows a device of this kind. The

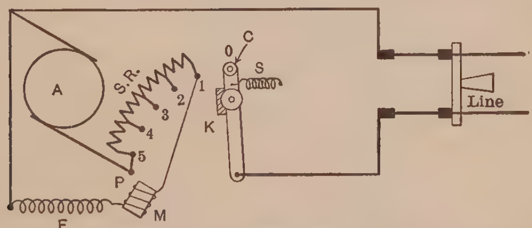


FIG. 142. The diagram of a starting box with a "No-field Release."

field current is led through a small electromagnet M on the starting box. The swinging arm C has a soft iron keeper K attached to it. When the arm has come into the running position and all the starting resistance SR is cut out, the keeper K comes in contact with the electromagnet M which holds the arm in this position, acting against the tension in the spring S.

If anything happens to break the current in the field coils F, the current in the electromagnet is also broken,

and the swinging arm is released and pulled away by the spring *S*. This action breaks the armature circuit and thus stops the motor.

A picture of this box is shown in Fig. 143. Note that there are but three connections to make to the box; one to **line,** one to **field** and one to **armature.** Such a box is called a **three-point box** and always has a **no-field release** device. The coil on it, therefore, must always be put in series with the field.

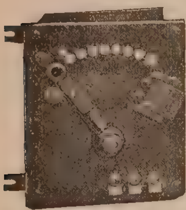


FIG. 143. A Cutler-Hammer 3-point starting box. "No-field" release.

Fig. 144 shows the diagram of the inside as well as the outside connections. Let us assume that the right-hand pole of the main switch is (+), as marked, and trace the current through the box and motor. The current enters the box at the point marked "line," and goes through the swinging arm on the box. If the arm is swung to touch the point (*a*), the current then divides at this point. Part of it goes through the "no-field release" coil to the point marked "field." From here it goes through the shunt field and back to the (–) side of the switch. The other part goes through the starting resistance to the point marked "arm." From here it goes through the armature of the motor and back to the (–) side of the switch.

Note that the point on the box marked "**line**" is connected to the line; the point marked "**field**" is connected to the field, and the point marked "**arm**" is connected to the armature. Thus we have **one** end of the line, **one** end of the armature, and **one** end of the field taken care of. The rest is just as simple. Join the **other** end of the armature to the **other** end of the field as at point (*b*), and then connect this juncture point to the **other** end of the line.

Note in Fig. 145 how the same scheme is carried out.

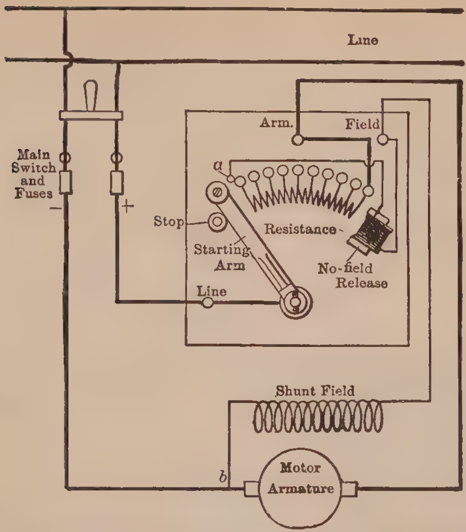


FIG. 144. Diagram of 3-point starting box. "No-field" release.

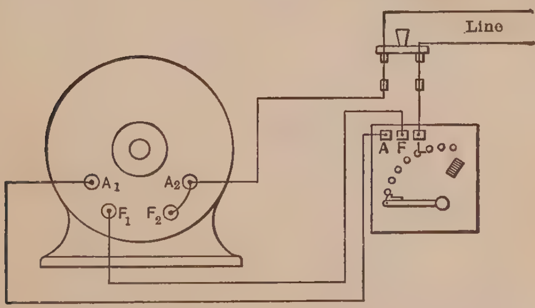


FIG. 145. Diagram of connections of shunt motor and 3-point starting box.

Point L on the box is joined directly to the line switch; point F is joined to F_1 (field terminal); point A is joined to A_1 (armature terminal). Then A_2 and F_2 (other field

and armature terminals) are joined together and brought directly to the other side of the line switch.

Prob. 15. Connect the shunt motor, Fig. 146, to the line through the starting box.

Prob. 16. Draw the inside connections of the box in Prob. 15.

Prob. 17. Draw the inside connections of the box in Fig. 145.

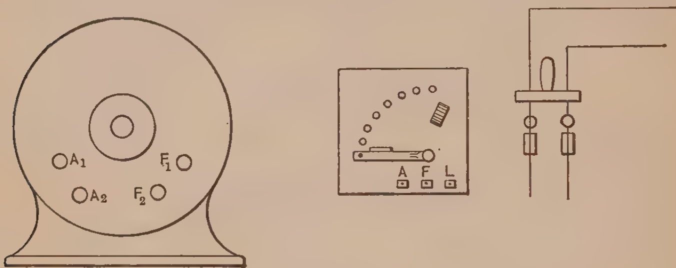


FIG. 146.

71. No-voltage Release. Sometimes, also, there is danger that the voltage will go off the line and, a few minutes later, be thrown on again. In the meantime, the motor

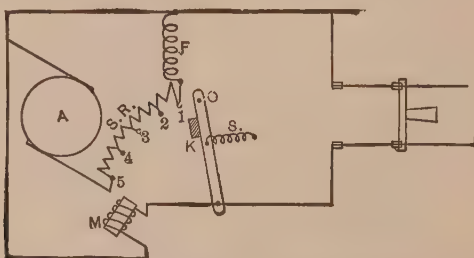


FIG. 147. Diagram of starting box with "no-voltage" release.

will have slowed down and possibly have stopped. If the voltage is now thrown on with the arm in the running position (with all the starting resistance cut out), the armature might be burned out. The above "no-field"

release is designed to take care of this emergency also; that is, to release the swinging arm and throw the motor off the line, if the voltage drops.

The usual "**no-voltage**" release, however, is arranged as in Fig. 147. Note that the only difference is that the coil *M* is no longer in series with the field, but is directly across the line. Thus both ends of the line must be brought to the box. This necessitates four connection points, two "**line**" points, an "**arm**" point and a "**field**" point. Such a box is called a **four-point box.** Fig. 148 shows the appearance of a box of this type, and Fig. 149 gives the internal and external connections to the motor and line.

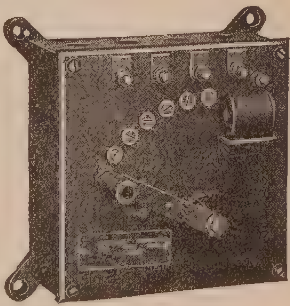


FIG. 148. A General Electric 4-point starting box. "No-voltage" release.

Assume the right-hand side of the switch to be (+) and follow the circuits through the box and motor. The current enters at the point marked "**line**" *C* and goes through the swinging arm to the button (*a*), as the arm is swung up. Here it divides into three branches, part of it going through the "no-voltage" release coil and directly to the other point marked "**line**" *B*, which is directly connected to the (−) side of the line. Another part of the current goes directly to the point marked "**field,**" then through the shunt field and to the (−) side of the line. The rest of the current goes through the starting resistance to the point marked "**arm,**" then to the armature of the motor and from there directly to the (−) side of the line.

The only difference, then, between a 4-point and a 3-point box, is the fact that in a 4-point the current through

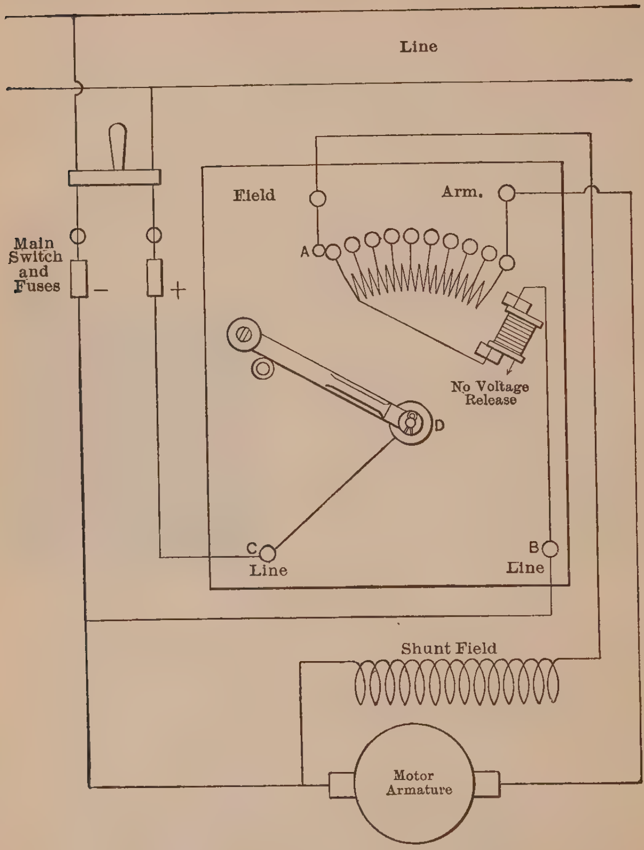


FIG. 149. Diagram of a 4-point starting box.
"No-voltage" release.

the field does not also go through the "release" coil. This type is generally preferred, as the "release" coil does not have to carry so much current as the "release" coil on a 3-point box.

The connections to be made, then, are:

One side of			Armature	to point on box marked					**"arm."**
"	"	"	Field	"	"	"	"	"	**"field."**
"	"	"	Line	"	"	"	"	"	**"line."**
Other	"	"	Line	"	other point			"	**"line."**

The other armature and field ends are to be connected together and go to the side of the line **not** connected to the swinging arm. (On a box where it is not indicated which "**line**" point is connected to the swinging arm, a voltmeter placed across points C and D will not register, if D is internally connected, as in the diagram, to C; between C and B the full voltage would show up on the voltmeter, and vice-versa.)

Prob. 18. In Fig. 150, connect the shunt motor, line and box.

Prob. 19. Show the internal connections of the box in Prob. 18.

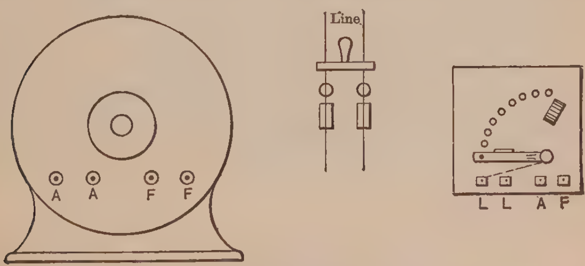


FIG. 150.

72. Series Motor. Starting Box. The starting box of a series motor is always a three-point box, but still always has a "no-voltage" release as is seen by Fig. 151.

Assume that the right-hand side of the switch is (+), and trace the current through the box and motor. From the (+) side of the switch two branches of the current flow. One

enters A_2, goes through the armature to A_1, goes to F_1 and through the field to F_2, goes to the point on the box marked "Arm or Field" (depending on whether (+) or (−) side of the switch is brought to A_2 or F_2). From this point, if the swinging arm is up, a current goes through the starting resistance to the swinging arm, to the point marked "Line." From here it goes directly to the (−) side of the switch.

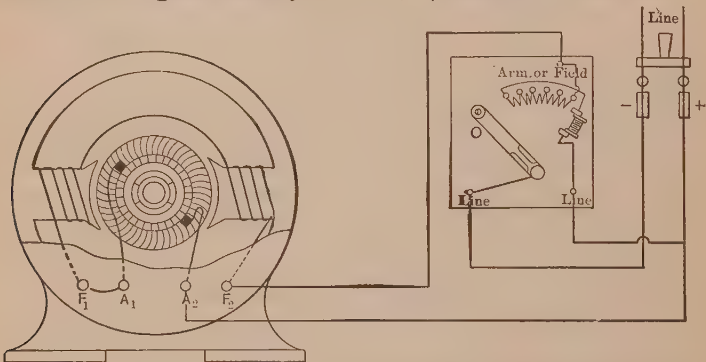


FIG. 151. The connections of a starting box for a series motor. "No-voltage" release.

The other current, starting from the (+) side of the switch goes to the other point on the box marked "Line," through the "no-voltage" release coil, through the swinging arm, and back through the previous "Line" point to the (−) side of the switch.

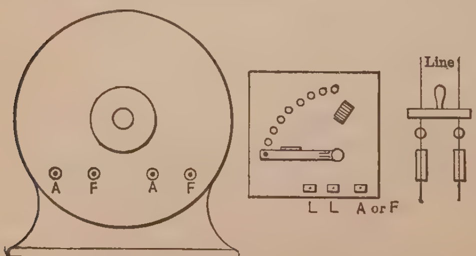


FIG. 152. Series motor and starter.

Prob. 20. Connect the series motor, Fig. 152, with the line through the box.

Prob. 20a. Show the internal connections of the box in Prob. 20.

Since a series motor when unloaded acts like a shunt motor with the field cut out, such a motor is never used unless geared, or directly connected, to its load, as in fans, trolley cars, hoisting cranes, etc.

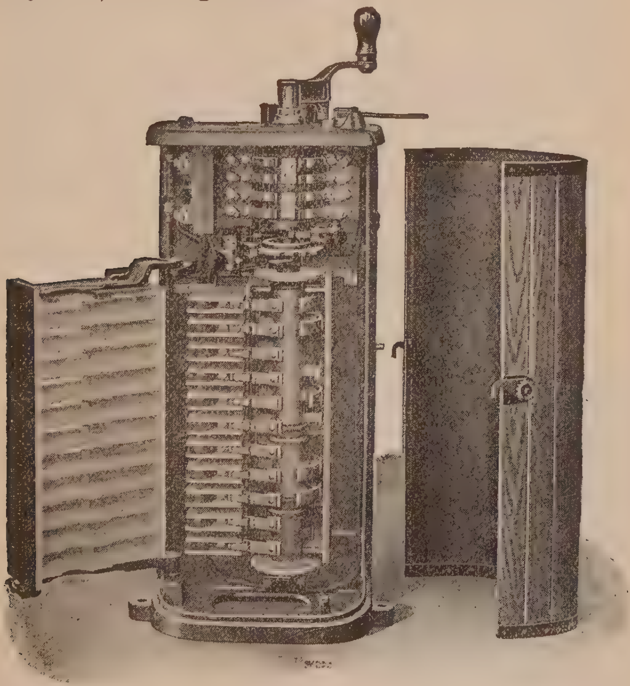


FIG. 153. General Electric controller for the motors of a trolley car; acts like a set of switches.

73. Series-Parallel Control for Electric Cars. Most electric cars have at least two motors, which are of the series type. The controller shown in Fig. 153 is in the front of the car, and is operated by the motorman. It acts as a set of switches which throw out the starting resistances, etc. When the controller handle is advanced

to the first notch, it places the two motors *A* and *B* in series with each other and with the starting resistance *SR*, as in Fig. 154. As the handle is advanced, it gradually cuts out the starting resistance until the car gets up a speed of about 10 miles an hour. Then the next notch puts the two motors in parallel with each other and again in series with the resistance *SR*, as in Fig. 155. If greater speed is desired, the resistance is again cut out by still further advancing the handle.

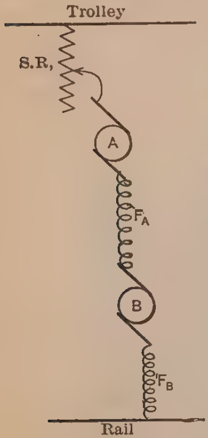


Fig. 154. The motors are in series with each other and with part of the resistance S.R.

The scheme of putting the two motors in series at the start allows the car to be started on half the current it would take to start with them in parallel, and thus preserves a more even distribution of current in the trolley system, and wastes much less power. It really makes one motor act as a starting resistance for the other, at the same time helping it to supply tractive effort.

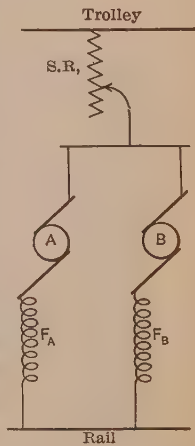


Fig. 155. The motors are in parallel with each other, but in series with part of the resistance S.R.

74. Caution in the Use of Series and Shunt Motors. A shunt motor races when the field is broken, if the armature circuit is not also broken. Therefore:

Never pull the field of a shunt motor.

A series motor races when there is no load connected to it. Therefore:

Never start an unloaded series motor and never remove all the load from a series motor while it is running.

A bad arc is formed between the first button and the contact on the arm of a starting box, if the arm is moved backwards. Stop a motor by pulling the main switch.

Never pull back the arm of a starting box.

The starting resistances are not made to carry a continuous current and will burn up if allowed to do so.

Never allow the arm of a starting box to remain more than 10 or 15 seconds on any intermediate button.

Note. Some boxes are made so that the motor can run on any point, but such boxes are always so marked.

75. "Overload" Release. There must also be some arrangement to prevent putting too much load on a motor,

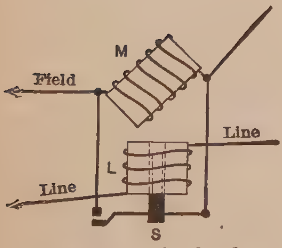


FIG. 156. Overload release of starter in Fig. 157.

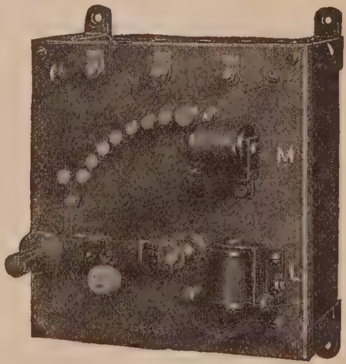


FIG. 157. General Electric motor starter with "No-field" and "Overload" releases.

thus causing the armature current to become excessive. For the greater the load on a motor, the greater the armature current. An **overload release** as shown in Fig. 156 takes care of this emergency, for a motor with a "No-field" release. A coil L of low resistance is placed in the motor

line, so that all the current taken by the motor must pass through it. When the current in the motor becomes excessive, the coil becomes so strongly magnetized that it sucks up the plunger S and short circuits the magnet

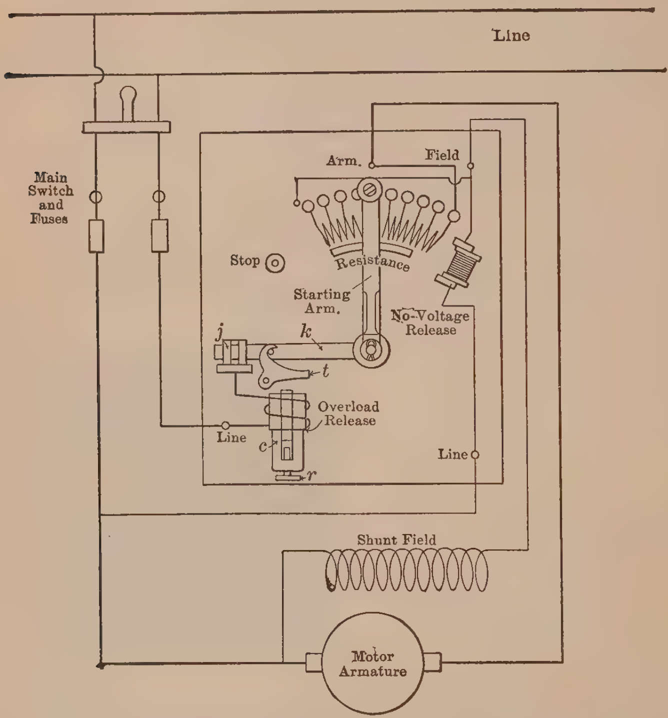


FIG. 158. Diagram of connections for motor starter with "no-voltage" and "overload" releases.

coil M. This destroys the magnetic force of M. The arm C is thus released and the current shut off from the motor armature and field. Fig. 157 shows the appearance of this box.

Fig. 158 shows another device for an "Overload" release which will work in connection with either a "No-field" or a "No-voltage" release. The swinging arm is made up of two parts, one the starting arm, and the other the lever (k). A spring tends to hold these together. Ordinarily the detent (t), however, holds the lever (k) in such a position that one end is held fast in the contact clips (j). But when the current becomes excessive, the electromagnet sucks up the iron core which is inside it, presses against the detent (t) and releases the lever (k), which flies up out of the clip (j) and joins the starting arm. Since all the current must enter the motor through the clip (j) and the lever (k), the power is off the motor when these are separated.

SUMMARY OF CHAPTER VI

GENERATOR — a machine delivering electric power when mechanical power is put into it.

MOTOR — a machine delivering mechanical power when electric power is put into it.

DYNAMO — a term which includes both motor and generator. The same machine may be used either as a motor or as a generator.

VOLTAGE is generated by wires wound on the armature cutting through a magnetic field; the brushes merely convey it to the outside line.

MAGNETIC FIELDS are produced by winding soft iron or steel with coils and sending an electric current through the coils. These fields are composed of magnetic force lines, which leave the North poles and enter the South poles, returning to the North poles through the iron or steel yoke of the machine.

DIRECTION of the current in the field coil determines the polarity of any pole. The rule for finding polarity is: Grasp the coil with the right hand so that the fingers point in the direction of the current in the coil and the thumb will point to the North pole.

THE POLES of a machine should be alternately North and South around the frame, and their strength depends upon the number of AMPERE-TURNS in the coils.

FIELD may be either:

- SEPARATELY EXCITED — when the field current comes from some outside source. This type is rarely used.
- SELF-EXCITED — when the field current comes from the armature of the machine itself.

Self-excited generators are divided into:

- SHUNT — when only a small part of the current going through the armature goes through the field coils.
- SERIES — when all the current going through the armature flows through the field as well as the line.
- COMPOUND — when two coils are used on each pole, one a series coil, and the other a shunt coil. This is the most common type of generator.

MOTORS are classified in the same manner as self-excited generators. Shunt motors are in most common use except for traction work.

VOLTAGE OF A GENERATOR must be " built up " from the small amount of residual magnetism left in the frame since last used. The voltage of a shunt generator can be controlled by means of an adjustable resistance inserted in the field circuit, which varies the field current and therefore the magnetic strength. When once " built up " and set at proper value by field resistance, the voltage of a shunt generator is nearly constant. It can be made absolutely constant by means of series coils in addition to the shunt coils.

COMMUTATING POLES are small poles on both generators and motors for the purpose of preventing sparking at the brushes. The coils on these poles consist of a few turns of heavy wire, and are always placed in series with the armature so that the same current flows through them as through the armature.

The polarity of commutating poles is determined as follows: Determine the polarity of the main poles; then place your hand on one pole after another in order, around the frame, in the direction in which the armature is to rotate. Every commutating pole will have the same polarity as the main pole which follows it, if the machine is a generator; or as the main pole just behind it, if the machine is a motor.

A machine generally has the same number of brushes as poles, not counting commutating poles. All (+) brushes are in parallel and all (−) brushes are in parallel.

RULES FOR PUTTING A GENERATOR INTO SERVICE. Follow back the leads from all terminals. Draw a sketch of the machine with leads and terminals marked as found. Make a diagram of the necessary connections and then follow the diagram.

Connect the terminals so that the series coils and the coils on the commutating poles are in series with the armature and main line switch.

Connect the shunt coils through the rheostat so that they are across the armature (or across armature and series coils if long shunt).

Be sure the coils give correct polarity. This can be tested by a compass using the shunt set alone and then the series set with very light load.

THE TURNING TENDENCY OR TORQUE in a motor armature is due to the action of the magnetic field on the armature conductors when they are carrying a current.

IN STARTING a motor, a resistance must be placed in series with the armature, because of the low resistance of the armature.

A BACK VOLTAGE is set up as the armature gets in motion, which opposes the flow of current in the armature to such an extent that the starting resistance can be cut out. Ohm's Law for this case can be stated:

$$\text{CURRENT (through armature)} = \frac{\text{LINE VOLTS (across armature)} - \text{BACK VOLTS (in armature)}}{\text{RESISTANCE (of armature)}}.$$

SPEED OF A SHUNT MOTOR can be INCREASED by inserting resistance in the field circuit. The weaker the magnetic field, the faster the speed. Fitted with this device the motor is an Adjustable Speed Motor. Such motors generally have commutating poles.

Can be DECREASED by resistance in series with the armature.

A NO-FIELD RELEASE is used on a shunt motor because the motor will speed up and wreck itself if the field happens to be destroyed. Consists of a coil on the starting box, in series with the field of the motor, which throws the motor off the line when anything happens to the field.

A NO-VOLTAGE RELEASE is often used on any kind of motor, which will throw the motor off the circuit if the voltage of the line drops below a certain point. This prevents the line voltage, as it comes on again, from being thrown across the motor after it has stopped. Consists of a coil directly across the line and not in series with the field.

A THREE-POINT STARTING BOX for shunt motors has three terminals and contains starting resistance and "No-field" release. Terminal marked "Field" is to be connected to the field terminal on the motor. The terminal marked "arm." is to be connected to the armature terminal on the motor. The terminal marked "Line" is to be connected to one side of the line. The other side of the line goes to the other armature and field terminals on the motor.

A FOUR-POINT STARTING BOX has four terminals and is fitted with a "No-voltage" release. The extra terminal is

connected to the line on the same side as the common armature and field connection on the motor.

A SERIES MOTOR "races" when it is unloaded and is therefore always attached to its load. Series motors are used mostly in traction work.

The two series motors of a trolley car are started in series with each other. The motorman by means of controller gradually cuts out resistance, then throws the two motors in parallel with each other, but again in series with the resistance. The final step cuts out the resistance and each motor is put directly across line.

AN OVERLOAD RELEASE automatically throws the motor from the line when the armature is carrying so much current that it is likely to burn. It consists of an electromagnet in the motor line, which works a tripping device if the current through it reaches a certain fixed value.

TO REVERSE THE DIRECTION OF ROTATION of a motor, reverse the direction of the current in EITHER the field or the armature, NOT IN BOTH.

CAUTION. Do not cut out current from the field of a shunt motor.

Do not start an unloaded series motor or take off the load of a series motor while running.

Do not stop a motor by pulling back the arm of the starting box. Pull the main switch or circuit breakers.

Do not allow the arm of a box designed "for starting duty only" to remain on intermediate points.

PROBLEMS ON CHAPTER VI

Draw diagrams of the electrical connections before making computations.

Prob. 21. A shunt generator with a brush voltage of 112 volts delivers 42 amp. to the line. The field coils have a resistance of 180 ohms.

(*a*) What current flows through the field?

(*b*) What current flows through the armature?

Prob. 22. What power does the generator of Prob. 21 deliver?

Prob. 23. What power is used to excite the fields of the generator in Prob. 21?

Prob. 24. The short-shunt compound generator of Fig. 126 maintains 115 volts across the terminals. The series field has a resistance of 0.25 ohm. The shunt field has a resistance of 250 ohms. Each lamp takes 2 amperes.

(*a*) How much current flows in the shunt field?
(*b*) How much current flows in the series field?
(*c*) How much current flows in the armature?

Prob. 25. How much power is lost in the series field of the generator of Prob. 24?

Prob. 26. How much power is lost in the shunt field of the generator of Prob. 24?

Prob. 27. The resistance of the armature of the generator in Prob. 24 is 0.24 ohm. How much voltage is required just to send the current through the armature?

Prob. 28. How much power is lost in the armature of Prob. 27?

Prob. 29. If the generator of Prob. 24 were connected as long shunt, answer (*a*), (*b*) and (*c*) of Prob. 24.

Prob. 30. How much power is lost in the series field of the generator of Prob. 29?

Prob. 31. How much power is lost in the shunt field of the generator of Prob. 29?

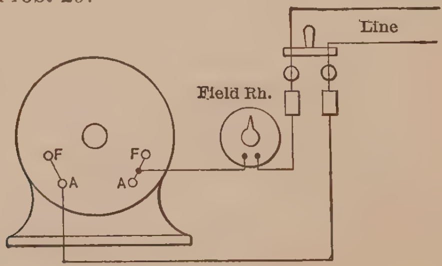


FIG. 159.

Prob. 32. Is the shunt generator in Fig. 159 connected to the line correctly? If not, make the proper connections.

Prob. 33. Is the shunt generator of Fig. 160 connected correctly? If not, make the proper changes.

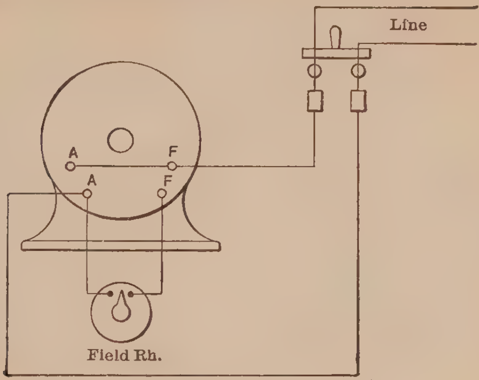


Fig. 160.

Prob. 34. Suppose that the upper wire in Fig. 160 (when generator is correctly connected) is (+) and it is desired to make it (–), what changes would you make?

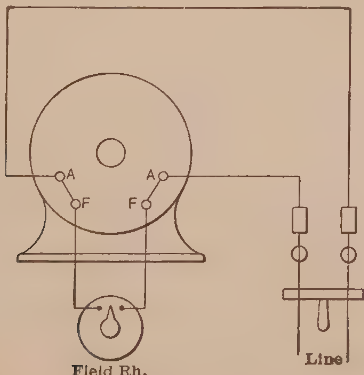


Fig. 161.

Prob. 35. Is the shunt generator in Fig. 161 correctly connected? If not, make the necessary changes.

Prob. 36. In the compound generator of Fig. 162, FF represent the shunt field terminals, and F_1F_1 the series field terminals. Are the connections right for a long shunt? If not, make the necessary changes.

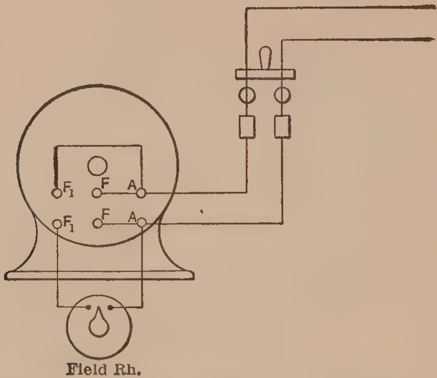


Fig. 162.

Prob. 37. Connect the generator of Prob. 36 as a short-shunt compound generator.

Prob. 38. Connect the generator in Fig. 162 as a simple shunt generator.

Prob. 39. If the shunt generator of Fig. 160 failed to "build up" after it was connected according to a correct wiring diagram, what change in the connections would you make?

Prob. 40. Connect the generator in Fig. 159 to run as a motor.

Prob. 41. Make the necessary changes in your diagram of connections for Prob. 40, to reverse the direction of rotation of the motor.

Prob. 42. Connect the generator of Fig. 160 to run as a motor. ("No-field" release on the box.)

Prob. 43. Show the necessary changes in the connections for motor of Prob. 42, to reverse the direction of rotation.

Prob. 44. Connect the generator of Fig. 161 to run as a motor. ("No-voltage" release on the box.)

Prob. 45. Show the necessary changes in your connections for Prob. 44, to reverse the direction of rotation.

Prob. 46. Connect the generator in Fig. 162 to run as a shunt motor. ("No-voltage" release on the box.)

Prob. 47. Is the shunt motor of Fig. 163 connected correctly? If not, make the necessary changes.

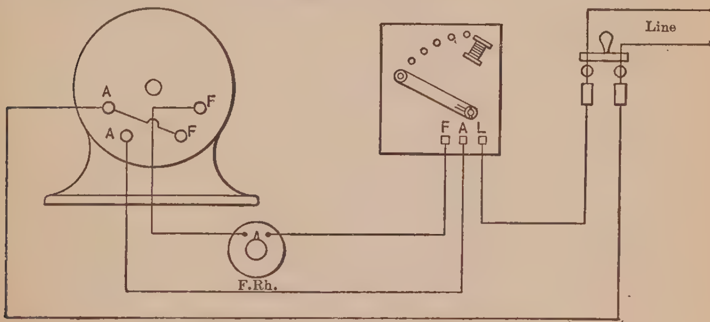


FIG. 163.

Prob. 48. Make the necessary changes in your diagram of connections for the motor of Fig. 163, to reverse the direction of rotation.

Prob. 49. Make a diagram showing a 220-volt shunt motor connected through a "No-voltage" release box and field rheostat to a three-wire system.

Prob. 50. Change the connections on the diagram of Prob. 49 so that the fields will be excited by 220 volts, and the armature by 110 volts.

Prob. 51. Change the connections on the diagram of Prob. 50 so that the fields will be excited by 110 volts and the armature by 220 volts.

Prob. 52. State the effect on the speed of the motor of:
(*a*) Changes made in Prob. 50.
(*b*) Changes made in Prob. 51.

Prob. 53. Make a diagram of the connections of the motor in Prob. 50, showing the necessary addition to the outfit and connec-

tion, if the motor speed was too high, and you were not allowed to use the 110-volt connections.

Prob. 54. Show a magnetic path in the commutating pole motor, Fig. 164, with two main poles. Mark the polarity of the commutating poles.

Prob. 55. Show the winding of all poles of the motor in Fig. 164, and the direction of current in the windings.

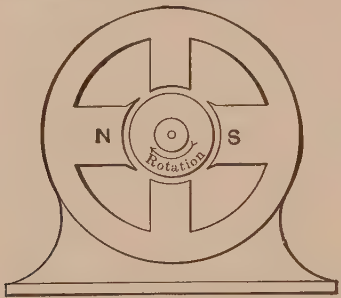


Fig. 164.

Prob. 56. If the machine in Fig. 164 is to run as a self-excited shunt generator, show:

(*a*) Polarity of commutating poles, and direction of armature rotation.

(*b*) Path of magnetic lines.

(*c*) Direction of current in windings on poles.

(*d*) Connections of windings on poles.

Prob. 57. What size copper wire must be run from the generator in Prob. 21, in order to meet the Underwriters' rules?

Prob. 58. When the generator of Prob. 57 is delivering full load, what is the "drop" along 400 ft. of main line?

Prob. 59. If it is desired to make the "drop" along 400 ft. of the line wire half what it is in Prob. 58, what size copper wire should be used?

Prob. 60. What size aluminum wire should be used in Prob. 57?

Prob. 61. How much power is lost in the 400 ft. of line wire in Prob. 58?

Prob. 62. If double the voltage were used in Prob. 58 to transmit the same power, how many watts would be lost in the 400 ft. of line wire?

Prob. 63. The line voltage is 112 volts. The resistance of the shunt field F, Fig. 142, is 200 ohms; of magnet coil M, 20 ohms. In the starting resistance SR the resistance from 1 to 2 is 5 ohms; from 2 to 3, 4 ohms; from 3 to 4, 3 ohms; from 4 to 5, 1 ohm; armature resistance is 2 ohms. The switch to power is thrown and contact c is swung to point No. 1.

(a) How many amperes flow through the armature?
(b) How many amperes flow through the field?

Prob. 64. When the armature of Prob. 63 has attained enough speed to set up a back voltage of 25 volts, the contact c is swung to point 2.

(a) How many amperes flow through the armature?
(b) How many amperes flow through the field?

Prob. 65. When the back voltage of armature in Prob. 64 is 48 volts, contact c is swung to point 3.

(a) How many amperes flow through the armature?
(b) How many amperes flow through the field?

Prob. 66. The armature of Prob. 65 attains a back voltage of 102 volts and contact c is swung to point 4. Answer (a) and (b) of Prob. 65.

Prob. 67. Armature of Prob. 66 attains a back voltage of 106 volts and contact c is swung to point 5. Answer (a) and (b) of Prob. 65.

Prob. 68. Armature resistance, Fig. 147, is 3 ohms. Field resistance is 224 ohms. Resistance of starting box is divided as follows:

1 to 2 = 2 ohms.
2 " 3 = 2 "
3 " 4 = 3 "
4 " 5 = 2 "
M = 1000 ohms.

Voltage of line = 115 volts.

(a) What is the starting current of the motor?
(b) If the back voltage of the motor is 75 volts when running on point 2 of the starting box, what current is the armature then taking?

Prob. 69. If the motor in Prob. 68 takes 3 amp. when running on point 4, what is its back voltage?

Prob. 70. A shunt motor takes a total current of 80 amp. from 115-volt mains. The resistance of the armature is 0.04 ohm. Resistance of field is 60 ohms.

(*a*) What current does each take?

(*b*) What power is lost in the field and armature?

FIG. 164a. General Electric starter panel.

Prob. 71. (*a*) What is the total power taken by the motor in Prob. 70? (*b*) Why is this greater than the power lost in the field and armature as computed in Prob. 70?

Prob. 72. What current does the field take in Prob. 68 (*a*) and (*b*)?

Prob. 73. Mark all terminal points on the board and the box in Fig. 164a and draw a diagram of the complete connections for the box, board and motor. Show inside connections of the box, and the back connections of the board, switch fuses, etc.

CHAPTER VII

LOCATING AND CORRECTING "TROUBLE"

It is the purpose of this chapter to discuss methods of locating and correcting troubles which appear in motors and generators after they have been put into service. It is intended to serve as a guide for men employed in installing and operating electric equipment. It is not meant for the designing room or testing department.

76. Signs and Causes. Certain happenings are the **signs** of trouble, the **causes** for which are more or less hidden. The expert can read these signs and go more or less directly to the cause of the trouble, just as a physician, by noting the patient's symptoms, can go more or less directly to the cause. As a rule the cause is very easy to remedy when once it has been found. The trick is to recognize the cause of the trouble from the sign. Consequently the greater stress will be laid on directions for tracing up the cause from the sign.

The following table is by no means complete, but it is believed that it covers more than nine-tenths of the troubles that are at all likely to arise. At any rate, it has this advantage, that it can be taken in at a glance, learned in an hour or so, and covers all the more common troubles.

The directions following the table show just what to do in each case, in order to trace up the cause of the trouble, which is indicated by the sign, and repair it.

The student should be careful to make his investigations exactly in the order in which they are set down. The troubles most likely to occur are not necessarily put first, but rather the easiest to recognize and repair, the object

always being to take the straightest path to the cause of the trouble, with as little interference to the service as possible.

It is to be noted in particular that these directions apply to shunt or compound machines of 110 or 220 volts only. In working around machines of higher voltage, much more care must be exercised than has been advised here to prevent electric shocks.

It will also be noted that it has been assumed that every manufacturer and user of electric power in quantity, either owns or has the use of a cheap portable ammeter and a two scale voltmeter of the same type.

DYNAMO TROUBLES

SIGNS	CAUSES
1. Sparking at Brushes.	1. Overload. 2. Brushes set wrong. 3. Poor brush contact. 4. Commutator rough or off center. 5. Weak field. 6. Armature winding broken or "short-circuited" by "ground" or "cross".
2. Noise.	1. Excessive vibration — unbalanced armature. 2. Rattle — loose parts. 3. Screeching — loose belt. 4. Flapping — loose lacing. 5. Bumping — too little end play. 6. Rubbing and pounding — armature hitting pole. 7. Squeaking — dry brushes.
3. Hot Armature Coils.	1. Overload. 2. Damp windings. 3. Short-circuited coils.
4. Hot Field Coils.	1. Too large field current. 2. Moisture in windings.
5. Hot Bearings.	1. Too little or improper oil 2. Grit. 3. Not enough end play. 4. Belt too tight. 5. Bearing too tight. 6. Poor alignment. 7. Crooked shaft. 8. Hot commutator. 9. Rough shaft.

6. Hot Commutator.	1. Near some hotter part of machine. 2. Sparking under brush. 3. Poor brush contact.
7. Fails to build up.	1. Field connections reversed. 2. Brushes not in proper position. 3. Wrong direction of rotation. 4. Speed too low. 5. Field circuit open. 6. Not enough residual magnetism. 7. Machine short-circuited.
8. Too low voltage.	1. Too much resistance in field. 2. Overload. 3. Brushes too far forward. 4. Speed too low. 5. Some reversed poles. 6. Some poles short-circuited.
9. Too high voltage.	1. Too strong field. 2. Brushes too far backward. 3. Speed too fast.
10. Motor fails to start.	1. Wrong connections. 2. Open circuits in connecting wires. 3. Field weak. 4. Overload. 5. Friction excessive.
11. Too high speed.	1. Too much field rheostat resistance. 2. Brushes too far forward. 3. Connections wrong. 4. Open field circuit.
12. Too low speed.	1. Overload. 2. Too little field resistance. 3. Brushes set wrong. 4. Excessive friction. 5. "Short" or "ground" in armature.

77. SPARKING AT BRUSHES

This may be due to any one or all of the following causes:

Test for and correct in the following order.

1. Overload.
2. Brushes set wrong.
3. Poor brush contact.
4. Commutator rough or off center.
5. Weak field.
6. Armature winding "open" or "short-circuited."

(1) To Test for Overload.

First: If the machine is a **generator** note the ammeter reading. If it is above the rating of the machine:

Make a rough estimation of the current taken by all appliances on the line. If the estimate agrees with the ammeter, the only remedy is to cut out some of these appliances. (Sometimes a slight shifting of brushes in the direction of rotation will help the machine to carry the load.)

Second: If the appliances call for much less than the ammeter reading, test for a ground as follows: Attach one terminal of a lamp or of a voltmeter to one line wire and the other terminal to a connection to the ground, such as a water pipe, gas pipe, etc. If the lamp glows brightly, or the voltmeter reads the voltage of the line, this means that the other line wire has a direct connection to the ground somewhere. Find this and repair it so that the voltmeter does not read when connected between either wire and the ground. A perceptible reading of the voltmeter, when attached to either line wire and the ground, shows wrong conditions somewhere. In this case, the line and fixtures should be

gone over thoroughly, special lookout being kept for contacts and places that appear warm to the hand. If the voltmeter shows no ground in the first test, look for leaks across some appliance, as a lamp socket, from one side to the other. This can generally be detected by the heating of the fixture.

Third: If the ammeter reading is not above the capacity of the machine, there still may be leaks, or grounds **near** or **at** the machine. If the machine is a motor, an ammeter inserted in series with it will tell when it is overloaded. If the overload is due to the machinery it is driving, the belt will have a tendency to squeak and be very taut on the tight side.

Fourth: Stop the machine and feel of the armature coils. If they are **all** too warm for the hand, it is a sure sign of overload on the machine, though there may be an overload which would not heat the coils.

If the overload is due to friction in the motor itself, the ammeter will show that a large current is taken by the motor, when it is run with its load disconnected. This "no load" current should not be more than 7 or 8% of the full load current.

To find and correct this friction, see page 181 for "Elimination of Noises."

(2) To Test Setting of Brushes. Rock the brushes slowly back and forth to see if a place can not be found where the sparking is much less. Look for a mark made at the factory, indicating the correct position. Do not rock the brush of a machine with commutating poles.

(3) To Test for Poor Brush Contact.

First: Note the appearance of the commutator. It should have a clean smooth chocolate color.

Second: See that the brushes bear evenly over all their bearing surfaces. Brushes **which do not,**

should be ground with sand paper till they fit the curvature of the commutator.

Third: Press each sparking brush separately. Note whether or not it fits its holder. Test the tension of the spring, noting whether tightening or loosening diminishes sparking.

(4) **To Test for Rough Commutator.** Touch the commutator, when running, with the tip of your finger nail and see if any roughness is felt. If so, stop the machine and examine the commutator. See if the copper has become worn down so as to leave the mica insulating strips up, or if a commutator bar has been loosened and become higher than the others. Note any rough spot due to the fusing effect of some momentary overload. Sandstone shaped to the curve of the commutator or sandpaper held in a wooden block, curved to fit the commutator, will remedy any of the above troubles. **Never use emery on a dynamo.**

Note. If grooves are worn in the commutator, or if it has become so much off center that the brushes move up and down as it revolves, it should be turned down, in a lathe or with a "truing" attachment. Plenty of end play will prevent grooves.

(5) **To Test for Weak Field.**

First: The speed will be excessive if the machine is a motor. The sparking will be worse in starting. A weak field is very likely due to wrong connections. Test the poles with a compass, using the shunt coils only. Then also using the series coils only. The poles should be alternately north and south around the frame.

Second: Broken circuit in a field coil (affecting all coils).

Test a motor by disconnecting the brushes, and suddenly opening the field circuit. If no spark

appears, the circuit is open. Test by disconnecting the field from the line. Try to send the current from a few cells in series with an ammeter through each coil separately as in Fig. 165. If the ammeter does not read when the arrangement is across any coil, it means that this coil is open.

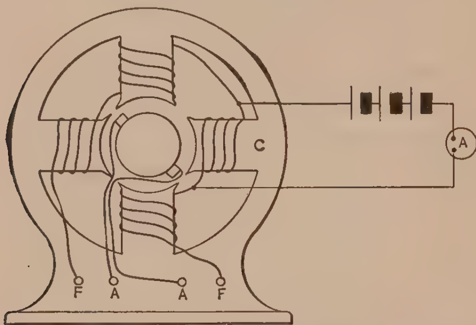


FIG. 165. Testing a field coil for an open circuit. If the ammeter does not read the field coil (*c*) is open.

Third: There may be a short circuit in one field coil (affecting one pole only).

To test for this: Hold a piece of iron, like a screw driver, near one pole after another. The pole which is weak probably has a short-circuited coil. Or send a current through all field coils and measure the voltage across each coil separately. If the voltage across any coil is low, it means that that coil is short-circuited.

To remedy these defects, it is usually necessary to rewind the coil.

(6) To Test for an Open- or Short-Circuited Armature Coil.

First: Short circuits in armature coils can usually be located by noting that some of the windings are very

warm after a run. This should usually be suspected as the cause, if the sparking is at one point only on the commutator. A more exact method of locating the coil is to connect a low voltage across the brushes when the machine is still, as in Fig. 166. Then touch adjacent segments all around the commutator with the two ends of voltmeter leads, using the low scale connections on voltmeter. The short-circuited coil will be between the two segments on which there is no reading, or a very low one.

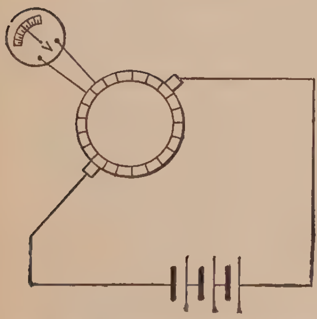


FIG. 166. Test for a short circuit in an armature. Coil is short-circuited if voltmeter reads very low.

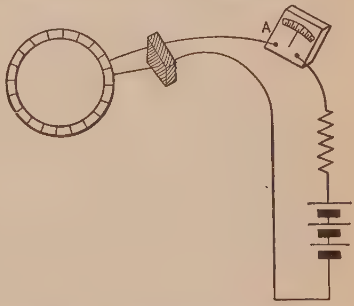


FIG. 167. Test for open armature coil. A coil is open if the ammeter reads lower than across the other coils.

Second: If the sparking is due to a break in the coil, it will be violent and will always occur at one place on the commutator. To test for an open coil, disconnect the brushes and send a low current through the ammeter and one coil after another as shown in Fig. 167. Two metal strips, separated by a wooden block and spaced to touch one segment each and span one gap, make a desirable pair of terminals. If the ammeter shows very much less reading when the metal strips are across any two segments,

then the coil which is connected between these two segments is open. Usually the only remedy for a break or a ground in a coil is to take the coil off and either rewind it or replace it by a perfect coil.

78. NOISE

All machines hum and vibrate a little, but when there are any unusual noises, such as those listed below, there is something wrong with the machine. This should be investigated and corrected.

1. Excessive vibration.	Means.	1. Poor alignment or unbalanced armature.
2. Rattle.		2. Loose parts.
3. Screeching.		3. Loose belt.
4. Flapping.		4. Poor belt fastenings.
5. Bumping against bearings.		5. Collar or coupling set wrong.
6. Rubbing and pounding.		6. Armature hits poles.
7. Squeaking.		7. Brush trouble.

(1) **Vibration.** Put your hand on the frame and, if the machine vibrates badly, change the speed, if possible (providing it does not disturb other running conditions). If the

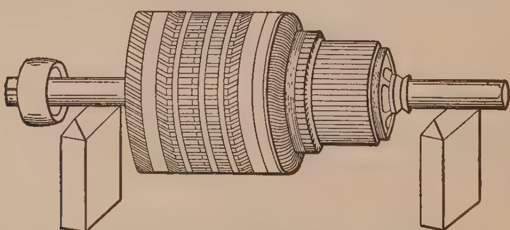


Fig. 168. Testing the balance of an armature.

machine still vibrates badly, change the alignment of one bearing. If the noise is not now stopped, change the other bearing. As a last resort, take the armature out and balance it on two knife edges as in Fig. 168. Roll it gently, setting it

several times with different parts uppermost. If it always tends to come to rest with the same part down, it means that the armature or pulley is not properly balanced. It can often be fixed by screwing nuts to the light side of the pulley or armature core. If this does not correct it, an expert must be sent for.

(2) **Rattle.** Look the machine over for loose nuts or other parts and tighten them.

(3) **Screeching.** A loose belt slips and makes a screeching noise. Tighten it. If it still slips, there is too much load for a pulley of the size used.

(4) **Flapping.** Poor lacing or loosened ends of belt flap when the loose place hits the pulley face. Stop the machine, examine the belt fastenings and repair them.

(5) **Bumping Against Bearings.**

First: Note whether or not this is due to the collar striking the bearing as the armature shaft travels back and forth lengthwise. If this is the cause, stop the machine and set the collar to allow more end play.

Second: If the machine is direct-connected to another, the pounding is probably due to poor alignment of the machines. When the machine is running, hold a pencil firmly fixed and gradually bring it near a smooth place on the coupling until it just touches. If on stopping the machine the mark made is found not to extend all around the coupling, it means that the coupling **bulges** at the point where the pencil touched. The machine should be realigned to force this point in a very little.

(6) **Rubbing and Pounding.** This is likely to be due to the armature rubbing on some pole face. Stop the machine and examine the pole face and the surface of the armature. If the armature winding is found to be loose, rebind it.

If the bearing babbitt is worn so that the armature is not in the center of the field gap, rebabbitt the bearings and adjust the armature to center by noting the clearance near each pole. It may be necessary in some cases to file the pole faces.

(7) **Squeaking.** This noise is generally due to one or more of the brushes.

First: Try lifting off one brush at a time (providing this does not open the circuit). Find the brushes which make the most noise, and readjust the tension, seeing that the brush holder allows for proper play.

Second: Apply a little vaseline with the finger to the commutator when running.

Third: Be sure that the brushes are set at the correct slant for the direction of rotation of the armature and that they fit the curvature of the armature. This curvature can be obtained by holding a strip of sandpaper firmly on the armature and turning the armature back and forth, letting the sandpaper wear down the brushes. On large machines, pull the sandpaper between the brush and armature, holding the brush firmly against the paper. The brushes on new machines always squeak more or less at first, but this should stop after running a day or two.

79. HOT ARMATURE COILS

When there is an odor of hot insulation about a machine, it is always well to stop the machine and feel of the armature coils. Heating may be due to some of the following causes:

Test for and correct as directed below:
1. Overload.
2. Dampness in coils.
3. Short-circuited coils.

(1) To Test for Overload. As on pages 175 and 176, for "sparking."

(2) To Test for Dampness in Coils. Look for any steaming of coils, and stop the machine and feel of the coils. If damp, bake in an oven or, better, send nearly full current through the armature for several hours. (Turn the armature slowly meanwhile.)

(3) To Test for a Short-Circuited Coil. See page 178 for "sparking."

80. HOT FIELD COILS

Heating of the field coils is usually due to one of the following causes:

Test for and correct in following order:
1. Too large current in coils.
2. Dampness in coils.

(1) To Test for Too Large Field Current.

First: Feel of all coils. If they are all hot, it means that the field current must be reduced, usually by means of field rheostat. If any coils are cool, it means that the cool ones are probably short-circuited.

Second: To be certain, measure the voltage across each coil. If any coil measures much lower than the others, take it off and look for a short circuit.

(2) To Test for Dampness in Coils. Note whether or not the coils steam, or feel damp to the hand. If so, send about three quarters of the full current through them for several hours.

81. HOT BEARINGS

If there is a smell of burning oil, or if the bearings are too hot for the hand to be held on them, then any of the following causes may be present:

Test for and correct in following order:

1. Too little oil of proper kind.
2. Grit in oil.
3. Not enough end play.
4. Belt too tight.
5. Bearing too tight.
6. Poor alignment.
7. Crooked shaft.
8. Hot commutation.
9. Rough shaft.

(1) **Oil Cups not Working.** Be sure all oil cups are full and delivering oil to the bearing, or that the oil rings rotate freely and bring up oil. (The oil may not be of the right quality and, as a last resort, should be changed on the advice of an expert.)

(2) **Grit in Oil.** See that the oil is free from grit by rubbing a little oil between the fingers. If not, stop the machine, clean the shaft and bearing thoroughly, and put in clean oil.

(3) **Not Enough End Play.** If the shaft collar keeps bumping against the bearing, there is not enough end play allowed for the armature "to pull into its field." Stop the machine and set the collar further from the bearing.

(4) **Belt too Tight.** Make certain that the belt is not so tight that it draws the shaft too hard against the bearings.

(5) **Shaft Too Tight in Bearings.** Loosen the cap of the bearings, and see if the bearing runs cooler.

(6) **Poor Alignment.** Loosen the lower bearing a little, allow it to take a new position and note whether or not the bearing runs cooler. If the machine is direct-connected to another, the alignment of the two machines with respect to each other may be poor. Note whether or not the coupling runs true, using the test on page 181. If not, make new alignment and test until the coupling does run true.

(7) **Crooked Shaft.** Observe the armature for evidences of wobbling, which means that the shaft is crooked. Stop the machine if this appears to be the trouble, and test, turning the armature by hand. This trouble can be remedied only by getting a new shaft from the manufacturing company.

(8) **Hot Commutator.** Stop the machine and feel of the commutator and bearing. If the commutator is evidently hotter than the bearing, the heat probably comes from the commutator. This trouble can be eliminated according to directions given below for hot commutators.

(9) **Rough Shaft.** While the machine is still, take off the cap and examine the shaft and bearings. If either shaft or bearing is rough, smooth it with a fine file.

82. HOT COMMUTATOR

A hot commutator may be due to one of the following causes:

Test for and repair in the following order:

1. Being near some hot part of machine.
2. Sparking under brushes.
3. Poor brush contact.

(1) **Test for Hotter Part.** Place your hand on the bearing near the commutator. If this is hotter than the commutator, heat comes from there, and it should be looked after according to directions given above.

(2) **Test for Sparks Beneath Brushes.** Sight between the brush and commutator and see if there are not a number of small sparks passing. If there are, apply the above methods for stopping sparks.

(3) **Test for Poor Brush Contact.**

First: Test the tension of the brushes by pulling up one after another (being careful not to open the circuit) and correct any defects.

Second: Note, by taking out the brush and examining the worn places on the contact surface, whether or not the brush is bearing on the commutator with its full face. If not, sandpaper the high spot down and fit the surface to the commutator as directed on page 177.

Third: If the commutator seems dry, apply a little vaseline to it with the finger tip.

83. GENERATOR FAILS TO BUILD UP

This is always due to the failure of the magnetism in the field to "build up," which may usually be traced to one of the following causes:

Test for and correct in the following order:

1. Reversed field connections.
2. Brushes in wrong position.
3. Wrong direction of rotation.
4. Speed too low.
5. Open field-circuit.
6. Not enough residual magnetism.
7. Machine short-circuited.

(1) **Test for Reversed Field Connections.** Reverse the connections of field to armature. (For the reason, see page 132.) If this does not cause the voltage to rise to the normal value, replace the connections as before.

(2) **Test for Position of Brushes.** While the machine is running, shift the brushes very slowly through their maximum arc. Replace the brushes to the mark made by the manufacturer, if the trouble is not corrected. Do not ever shift the brushes of a machine having commutating poles.

(3) **Test for Direction of Rotation.** Reverse the direction of rotation of the armature. If this does not correct the trouble, change back again to the former direction.

(4) **Test for Too Low Speed.** Take the speed of the shaft with a speed counter or indicator and compare with the rated speed of the machine as a generator. Note that the same machine must run much faster as a generator than as a motor. Try the effect of higher speed.

(5) **Test for an Open Field-Circuit.**

First: Stop the machine and disconnect the armature. Send a current from a battery through the field. If there is not a good spark when the circuit is now broken, it means that there is a break in the field circuit.

Second: Test each field coil in the same way, or as in paragraph 77, page 177, and find where the break is. If the break is on the inside of any coil, this coil must be replaced or rewound.

(6) **Test for Low Residual Magnetism.** Connect up the machine as at the start, but leaving open one field connection (*A*) to the armature, Fig. 169. Connect in a few dry cells so as to send a current through the field while this connection (*A*) to the armature is open. Start the machine and, if the voltage begins to pick up when the remaining field connection is made, pull the dry cells out. If not, try connecting the cells to send the current in the reverse direction through the fields.

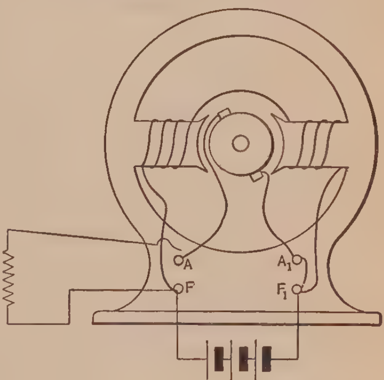


Fig. 169. Test for low residual magnetism.

(7) **Test for Short Circuit of Machine.**

First: Pull the line switch. This disconnects all load from the machine. If the generator now "builds up," throw the line switch. If the voltage does not die out again, it means that there was too large a starting load on the machine. If there is a short circuit on the line, the circuit-breaker will trip, or the fuses will blow

as the load is thrown on. This trouble should be located and corrected according to the directions on page 175 before voltage is again thrown on the line.

Second: If the machine fails to "build up" with the line switch open, there is probably a short circuit at the machine. Stop the machine and place a strip of paper under the brushes, leaving all connections ready for running. Connect a few battery cells in series with an ammeter to the terminals of the generator. If the ammeter reads more than the small current which the field coils should take, it is proof that there is a short circuit in the machine. This will usually be found to be in the "grounding" of terminals, or connections, to the frame. Whether these grounds are in the armature or the field, can be determined as follows:

Third: Leaving the paper under the brushes, make a careful inspection of all leads and terminals for evident grounding. If no places can be found, disconnect the armature from the field. Connect a few cells in series with a low reading voltmeter, touch the free terminal of the cells to the armature terminal, and the free end of the voltmeter to the frame, being sure to make good contact with some clean metal (see Fig. 170). A reading means a ground in the armature terminals, brush holders or in the lead wires from the brushes. Remove the brushes and test between the frame and brush holders by placing the battery terminal on the brush

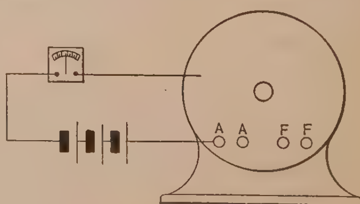


Fig. 170. Test for "ground" in brushes, leads, or terminals.

holder and the voltmeter terminal on the frame. The same test can be made between; (*a*) Commutator segment and shaft; (*b*) Field terminals and frame.

Note. If a pressure of 220 or 110 volts is available for this test, it should by all means be used, using a voltmeter of sufficient range, instead of cells and a low range voltmeter.

Note. Two grounds are necessary to make a short circuit. When it is found that a ground exists in either the armature or the field circuit, before removing the coils, be sure that the trouble is not at the terminals.

84. VOLTAGE OF GENERATOR TOO LOW

This may be due to any of the following causes, most of which produce a weak field.

Test for and correct in the following order:
1. Too much resistance in field.
2. Overload.
3. Brushes placed wrong.
4. Speed too low.
5. Reversed poles.
6. Pole "short-circuited."

(1) Too Much Resistance in the Field.

First: Cut out gradually all resistance of the field rheostat.

Second: Look for a loose or corroded field connection.

(2) Test for Overload. See page 176, for overload producing "Sparking at brushes."

(3) Test for Position of Brushes. Shift the brushes a little against the rotation of the armature, especially if the generator has commutating poles.

(4) Test for Too Low Speed. See page 186, on low speed as a cause for failure to "build up."

(5) Test for Reversed Poles. In multipolar machines, test each pole with a compass. Poles should alternate north and south around the frame. Reverse the connections on any poles found to be of wrong polarity.

(6) **Test for a Short-Circuited Field Coil.** See page 183 for test of short circuit in case of "hot field coils."

85. GENERATOR VOLTAGE TOO HIGH

This may be due to any of the following causes:

Test and correct in the following order:
1. Field too strong.
2. Brushes in wrong position.
3. Speed too fast.

(1) **Test for Too Strong Field.** Gradually cut in all of the field rheostat resistance.

(2) **Test for Brush Position.** Shift the brushes a little in the same direction as the armature rotates, especially if the generator has commutating poles.

(3) **Test for Speed.** Take the speed with a speed counter or indicator and compare with the speed rating of the machine. If possible, lower the speed.

86. MOTOR FAILS TO START

If the motor does not start when the arm of the starting box reaches the third point, pull the main switch and release the arm. Failure may be due to the following causes:

Test for and correct in order given:
1. Wrong connections.
2 Open circuits.
3. Weak field.
4. Overload.
5. Friction excessive.

(1) **Wrong Connections.** Go over all connections carefully, being sure that they agree with the diagrams and principles given in Chapter VI. Note especially the connections to the starting box, if it is an unfamiliar make. Be sure that there is no load on the motor.

(2) **Test for Open Circuits.**

First: With the line switch closed, place a voltmeter across the line between the fuses and machine. If it

does not indicate, look for blown fuses, open circuit breakers, etc.

Second: Put a voltmeter across the armature terminals, and try starting the motor, as before, not exceeding three points on the box, if motor does not start. If the voltmeter does not read, there is either a wrong or a broken armature connection.

Third: Put a voltmeter across the field terminals, and try starting the motor, not exceeding three points on the box if motor does not start. If the voltmeter does not read, there is either a wrong or a broken field connection. If the voltmeter reads the apparently correct values, proceed with the following tests.

(3) **Test for Weak Field.** Cut out all resistance in the field rheostat.

(4) **Test for Overload.** Remove the load and try starting the motor. Put the load on slowly. If the fuses or circuit breakers blow, the load is too heavy.

(5) **Test for Friction.**

First: Start the motor with the load off, putting an ammeter in the motor line. If the current taken by the motor is more than 6 or 8% of the full load current, there is too much friction present.

Second: Continue the test as on page 175 in tests for overload of motors producing " sparking at brushes."

87. MOTOR SPEED TOO HIGH

This is usually due to a weak field. It may have any of the following causes:

Test for and correct in order given:

1. Too much field-rheostat resistance.
2. Brushes too far forward.
3. Connections wrong.
4. Open field-circuit.

(1) **Test for Rheostat Resistance.** Cut out all the resistance of the shunt field rheostat.

(2) **Test for Position of Brushes.** Shift the brushes against the direction of rotation especially if the motor has commutating poles.

(3) **Test for Wrong Connections.** Go over all connections and make them agree with the directions in Chapter VI.

(4) **Test for Open Field-Circuit.** An open field-circuit makes an unloaded shunt motor race and spark badly. With the armature leads disconnected, put voltage across the field terminals. If there is no spark when the circuit is now broken, there is an open circuit in the field. (See test for location of break on page 178, in "Test for Weak Field.")

88. MOTOR SPEED TOO LOW

This fault may be due to the following causes:

Test for and correct in order given below:

1. Overload.
2. Field resistance too small.
3. Brushes set too far backward.
4. Excessive friction.
5. Short circuit in armature.

(1) **Test for Overload.** Test as on page 175, for "Overload."

(2) **Test for Too Small Field Resistance.** Cut in more resistance on the field rheostat.

(3) **Test for Brush Setting.** Shift the brushes a little forward, especially if the motor has commutating poles.

(4) **Test for Excessive Friction.** Test as on page 191, for "Excessive Friction."

(5) **Test for Short Circuit in Armature.** Test as on page 178, "for Short or Ground in Armature Circuit."

SUMMARY OF CHAPTER VII

Note carefully the SIGNS of trouble. Make tests for the CAUSES of trouble in the order given. By this method one cause after another is eliminated and the final cause is certain to be found.

TO AVOID TROUBLE.

First: Keep the commutator clean. The load which a machine will carry and the length of time for which it will carry the load is, as a rule, limited by the sparking and heating of the commutator and brushes. It is of prime importance, then, to keep the commutator clean and smooth and the brushes well fitted both to commutator and brush holder, so that they may work under the best possible conditions.

Second: Keep all parts of an electric machine dry.

CHAPTER VIII

BATTERIES

89. Generators versus Batteries. There are two ways of generating electric pressure commercially.

One method is by moving the wires wound on an armature core in the strong magnetic field of the poles. Machines built on this principle are called **electric generators.**

The other way is by chemical action. Devices using this principle are called **electric batteries.**

When electric power is to be generated in any quantity, the generator is used. When a very small amount of power is required, as for ringing bells, operating spark coils, etc., batteries are often used, although small **magneto-generators,** or generators with permanent magnets for poles, are also in general service.

It has been found that if we put two electrical conductors, such as a zinc plate and a copper plate, into a weak solution of some acid, such as sulphuric, so that they do not touch each other, an electric pressure is set up between the plates. The copper plate becomes (+) and the zinc (−), so that when the plates are joined by a wire a current flows from the copper to the zinc.

90. Electromotive Force. The electric pressure thus set up is called the **electromotive force** and is measured in volts. It is really the electric **moving force,** which **moves** the current through the circuit. The total voltage generated by a dynamo is also called its electromotive force, although the term is not used as often as with batteries. The letters "e.m.f." are generally used instead of the words "electromotive force."

The e.m.f., then, is the voltage across the terminals of the cell when it is not delivering current, hence it is sometimes called the "open-circuit voltage." To find the electromotive force, or open-circuit voltage, of a cell, it is necessary merely to place a low reading voltmeter across the terminals when the cell is not delivering any current.

Almost any two electrical conductors might be used for plates instead of zinc and copper, the only requirement being that the two must not be the same material. Likewise other liquids might be used in the place of the sulphuric acid, the requirement here being that the liquid must attack one of the metals chemically.

The e.m.f. set up depends entirely upon what plates and chemical are used. The size of the plates makes absolutely no difference. A large battery cell of the same materials gives exactly the same e.m.f. as a small one.

The e.m.f. of a zinc, copper, sulphuric acid cell is about 1 volt, regardless of size.

The e.m.f. of a zinc, carbon, chromic acid cell is about 2 volts, regardless of size.

The e.m.f. of a zinc, carbon, sal ammoniac cell is about 1.5 volts.

91. Wet Cells and Dry Cells. The cells most commonly used for bells, annunciators, fire alarms and gasoline engine ignition are of two types, the **wet** and the **dry.**

Both types make use of about the same materials, zinc, carbon, and a solution of sal ammoniac, with some other chemicals added to improve their action.

In the wet cell, three or four ounces of sal ammoniac are dissolved in water and poured into a glass jar. The carbon is commonly put in a porous cup and placed in the center. The zinc, either in the form of a rod or of a hollow cylinder, is held away from the carbon by the cover and the porous cup.

In the so-called dry cell, the sal ammoniac water solution is made into a paste by means of plaster and put into a zinc can, which forms the negative plate. The carbon is then placed in the center of the paste and held away from the zinc by the hardened paste and insulating cover. Thus this type is not really dry, but the fluid is held by the plaster so that it will not run out, very much as wet ink is held by blotting paper.

In the case of both wet and dry cells, it is the zinc which is attacked and consumed by entering into chemical composition with the sal ammoniac. So the zinc and the sal ammoniac gradually disappear. To replace these in a wet battery, more fluid is added and another stick or plate of zinc is put in. But since the zinc forms the container in the dry cell, this battery has to be thrown away when the zinc is about used up. On the other hand, the cost of a dry cell is very little, and their convenient form makes them very popular. Both the wet and dry cells described above have the same e.m.f. of about 1.5 volts.

92. Internal Resistance. Although the two cells just mentioned have the same e.m.f., they are very different in another respect. The resistance of the path through the liquid, from the zinc to the carbon, is very high in the wet battery, being between 0.5 and 4 ohms. This is called the **internal resistance** of the cell. In the case of a good dry cell, it is usually less than 0.1 ohm.

Since some of the e.m.f. of the cell must always be used up in sending a current through this internal resistance, it is essential that it should be as low as possible, especially when the battery is to deliver much current.

93. Current Delivered by Cell. Of course the amount of current delivered by a cell obeys Ohm's law absolutely, and depends upon the e.m.f. of the cell and the resistance of the **entire** circuit.

Now a cell has a certain available voltage, that is, the e.m.f., with which to send a current through the two parts of a circuit, which consist of the part outside the cell and the part inside the cell. The strength of the current depends, then, upon how great the resistance of these two parts is. The current is always equal to the e.m.f. divided by the sum of these two resistances. That is,

$$\text{(total) current} = \frac{\text{(total) voltage}}{\text{(total) resistance}}.$$

In this case,

$$\text{(total) current} = \frac{\text{e.m.f. (which is total voltage)}}{\text{internal resistance} + \text{outside resistance}}.$$

Example 1. A cell has an e.m.f. of 1.50 volts and an internal resistance of 0.20 ohm. What current will the cell send through a 2.80-ohm wire?

$$\text{Current} = \frac{\text{e.m.f.}}{\text{internal resistance} + \text{outside resistance}}$$

$$= \frac{1.50}{0.20 + 2.80}$$

$$= \frac{1.50}{3.00} = 0.5 \text{ amp.}$$

Example 2. If the cell in Example 1 had an internal resistance of 4 ohms, what current would it send through the same wire?

$$\text{Current} = \frac{\text{e.m.f.}}{\text{internal resistance} + \text{outside resistance}}$$

$$= \frac{1.50}{4 + 2.8}$$

$$= \frac{1.50}{6.80} = 0.221 \text{ amp.}$$

Note that with the same e.m.f. and the same wire, less than half the current flows in the second example, because the internal resistance is so much higher.

Prob. 1. What current will a battery cell of 1.28 volts e.m.f. and 2.4 ohms internal resistance send through a miniature lamp of 8 ohms resistance?

Prob. 2. A dry cell has an e.m.f. of 1.51 volts and an internal resistance of 0.08 ohm. What current will it deliver through a 10-ohm wire?

Prob. 3. What current will the cell of Prob. 2 deliver through a 0.1-ohm wire?

Prob. 4. What current will the cell in Prob. 2 deliver through a 0.01-ohm wire?

Prob. 5. What current will the cell in Prob. 2 deliver through a short circuit; that is, a wire of practically no resistance?

Prob. 6. A wet cell has the same e.m.f. as the cell in Prob. 2, but an internal resistance of 4 ohms. What current will this cell deliver through a 10-ohm wire?

Prob. 7. What current will the cell in Prob. 6 deliver through a short circuit?

Prob. 8. What respective currents will the cells in Prob. 2 and 6 deliver through 100 ohms?

It is well to note in the above problems, that when the external resistance is high, it does not make very much difference with the current whether the internal resistance of the cell is high or low. But if the external circuit has a low resistance, it makes a great difference in the current whether the cell used has a high or a low internal resistance.

94. Terminal Voltage. It is interesting to observe that the small current delivered by a cell of high internal resistance even on short circuit is due to the fact that so much of the e.m.f. of the cell is used up in sending the current through the internal resistance, that but little is left to send the current through the external resistance. The voltage used in sending the current through the internal resistance is, of course, found by Ohm's law, just as is the voltage to send a current through any other kind of resistance.

Example 3. A cell has an internal resistance of 1.2 ohms. How many volts of its e.m.f. are used to send the current through the cell itself when it is delivering 0.5 amp.?

$$\begin{aligned} \text{Voltage} &= \text{current} \times \text{resistance} \\ &= 0.5 \times 1.2 \\ &= 0.60 \text{ volts.} \end{aligned}$$

Example 4. If the cell in Example 3 had an e.m.f. of 1.48 volts, how many volts would it have across the outside circuit?

It is plain that, if the cell has an e.m.f. of 1.48 volts and uses 0.60 volt of this e.m.f. to send a current through itself, then it can have but 1.48 − 0.60, or 0.88 volt left to send a current through some outside circuit. That is, if we put a voltmeter across the terminals of this cell on open circuit, we should find it had a voltage or an e.m.f. of 1.48 volts. But if we connected a wire across it and allowed 0.5 amp. to flow as in the example, then the voltmeter would read only the 0.88 volt used in sending current through this outside wire. This is called the **terminal voltage** of the cell for a certain current. If it were possible (which it is not) to place a voltmeter across the inside of the cell, we should find that the other 0.60 volt, of the 1.48 volts which the cell has, is used to force the current through the inside of the cell. The whole e.m.f. of 1.48 volts is then used up as follows:

Volts to force current through wire	= 0.88 volt.
" " " " " cell	= 0.60 "
Total voltage or e.m.f.	1.48 volts.

This is true in the case of every cell delivering a current.

To find what terminal voltage a cell will have when sending a given current through a line, we must subtract the drop across the inside of the cell from the e.m.f.

That the terminal voltage of a given cell depends upon what current it is delivering, can be seen from the following examples.

Example 5. A cell of 0.14 ohm internal resistance and 1.5 volts e.m.f. is delivering 10 amp. What is the terminal voltage?

Volts used in overcoming int. res. = current × internal resistance
= 0.14 × 10
= 1.40 volts.

$$\begin{aligned}\text{Terminal voltage} &= \text{e.m.f.} - \text{volts used on internal resistance}\\ &= 1.5 - 1.4\\ &= 0.1 \text{ volt.}\end{aligned}$$

Example 6. If the cell of Example 5 is delivering 5 amp. only, what will be its terminal voltage?

$$\begin{aligned}\text{Volts used across int. res.} &= \text{current} \times \text{internal resistance}\\ &= 5 \times 0.14\\ &= 0.70 \text{ volt.}\end{aligned}$$

$$\begin{aligned}\text{Terminal voltage} &= \text{e.m.f.} - \text{volts used across internal resistance}\\ &= 1.50 - 0.70\\ &= 0.80 \text{ volt.}\end{aligned}$$

We see that, by reducing the current to one-half, we greatly increased the terminal voltage. We may say, then, that:

The smaller the current a cell is delivering, the greater its terminal voltage.

Prob. 9. What is the terminal voltage of a cell which is delivering 4 amp. if it has an e.m.f. of 1.2 volts and an internal resistance of 0.2 ohm?

Prob. 10. Could the cell in Prob. 9 deliver 8 amp.? If so, what would be its terminal voltage? If not, why not?

Prob. 11. What maximum current could the cell of Prob. 9 deliver?

Prob. 12. What would be the terminal voltage of the cell in Prob. 9 when it was delivering its maximum current?

Prob. 13. What would be the terminal voltage of the cell in Prob. 9 when it was delivering no current?

Prob. 14. A cell has an internal resistance of 2.3 ohms and an e.m.f. of 1.2 volts. The external circuit has a resistance of 5 ohms. Find:

(*a*) The current flowing.
(*b*) Voltage drop across the internal resistance.
(*c*) Terminal voltage.

Prob. 15. A cell is delivering 3.2 amp. Its internal resistance is 0.3 ohm, and its e.m.f. is 1.24 volts. What will a voltmeter read if put across the terminals of the cell?

Prob. 16. What is the external resistance in Prob. 15?

Prob. 17. Through what external resistance will a cell deliver 4 amp. if its e.m.f. is 1.4 volts and its internal resistance 0.12 ohm?

Prob. 18. The cell in Fig. 171 has an e.m.f. of 1.35 volts. The ammeter reads 0.31 amp. What is the internal resistance of the cell?

Prob. 19. What would a voltmeter read if put across the cell connected as in Fig. 171?

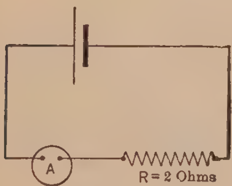


Fig. 171.

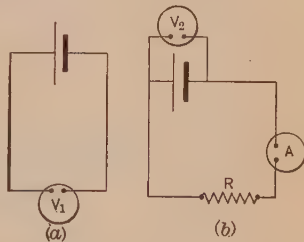


Fig. 172.

Prob. 20. A voltmeter put across a cell as in Fig. 172 (*a*) reads 1.46 volts. When put across the same cell connected as in Fig. 172 (*b*) the voltmeter reads 0.92 volt. The ammeter *A* reads 6.4 amp. Find:

(*a*) The e.m.f. of the cell.
(*b*) Internal resistance of cell.
(*c*) Resistance of *R*.

95. Best Arrangement of Cells. Suppose that we wish to send as large a current as possible through a telegraph relay which has 100 ohms resistance and have but 8 cells, each of 1.5 volts e.m.f. and 2 ohms internal resistance. How shall we arrange them?

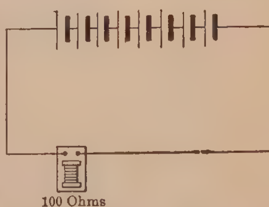


Fig. 173. Eight cells joined in series are sending current through the coil.

Suppose that we put them all in series as in Fig. 173. The voltage across a series circuit, we remember, is the sum of the voltages across all

the parts; so the e.m.f. of the combination of cells will be the sum of the e.m.f.'s of the cells, or

$$8 \times 1.5 = 12 \text{ volts.}$$

This is the only e.m.f. in the circuit, and is therefore the e.m.f. of the entire circuit.

The resistance of a series circuit is the sum of the resistances of all the parts, or

$$(8 \times 2) + 100 = 116 \text{ ohms.}$$

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$
$$= \tfrac{12}{116}$$
$$= 0.104 \text{ amp.}$$

Now suppose that we put the cells in parallel as in Fig. 174. Since the voltage across a parallel combination is the same as the voltage across each branch, the combined e.m.f. of the cells is the same as the e.m.f. of one cell, that is, 1.5 volts.

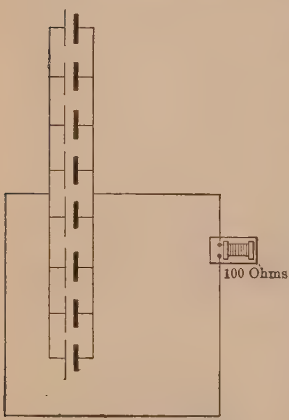


FIG. 174. Eight cells joined in parallel are sending current through the coil.

But the resistance of a parallel combination, made up of equal resistances, is the resistance of one piece divided by the number of pieces; therefore the internal resistance of the 8 cells in parallel, each having 2 ohms internal resistance, is

$$\frac{2}{8} = \frac{1}{4}, \text{ or } 0.25 \text{ ohm.}$$

This parallel combination, however, is in series with the

100 ohms of the relay, therefore the entire resistance of the circuit is

$$100 + 0.25, \text{ or } 100.25 \text{ ohms.}$$

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$

$$= \frac{1.5}{100.25}$$

$$= 0.0149 \text{ amp.}$$

The current when the cells were in series was 0.104 amp., or about 7 times as great as when the cells were in parallel. As a general rule, it may be stated that:

The series arrangement of cells gives the greatest current when the external resistance to be overcome is large.

Suppose, however, that we wanted to use the same cells to send the greatest current possible through a coil of 0.2 ohm resistance. If we arranged the cells all in parallel, as in Fig. 175, the voltage of the circuit would be the voltage of one cell alone, or 1.5 volts.

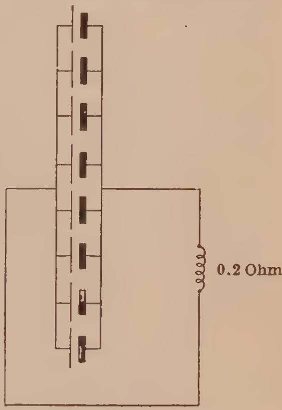


FIG. 175. The eight cells are in parallel.

The resistance of the cells would be $\frac{2}{8}$, or 0.25 ohm. The resistance of the entire circuit would then be $0.25 + 0.2 = 0.45$ ohm.

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$

$$= \frac{1.5}{0.45} = 3.33 \text{ amp.}$$

If we arranged the cells all in series, as in Fig. 176, the e.m.f. of series combination of cells would be

$$8 \times 1.5, \text{ or } 12 \text{ volts.}$$

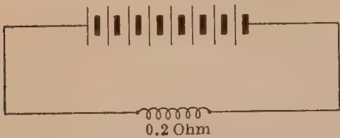


FIG. 176. The eight cells are in series.

The internal resistance of cells would be 8×2, or 16 ohms. Resistance of entire circuit would be

$$16 + 0.2 = 16.2 \text{ ohms.}$$

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$

$$= \frac{12}{16.2} = 0.74 \text{ amp.}$$

Here the current for the parallel arrangement was 3.33 amp. or about $4\frac{1}{2}$ times as great as the series. This is exactly the opposte of the case where we had 100 ohms for an external resistance instead of 0.2 ohm.

As a general rule, then, it may be stated that:

The parallel combination of cells gives the greatest current when the external resistance is very small.

Suppose again that we wished, with the same batteries, to ring a bell of 4 ohms resistance, which is neither very high nor very low, with the greatest current possible.

If we used them all in series the voltage would be

$$8 \times 1.5, \text{ or } 12 \text{ volts.}$$

The internal resistance of cells would be

$$8 \times 2, \text{ or } 16 \text{ ohms.}$$

The resistance of entire circuit would be

$$16 + 4 = 20 \text{ ohms.}$$

Current (through entire circuit)

$$= \tfrac{12}{20} = 0.6 \text{ amp.}$$

If we used them all in parallel;

Voltage of the combination of cells = 1.5 volts.

Internal resistance of cells = $\frac{2}{8}$ = 0.25 ohm.

Resistance of entire circuit = 0.25 + 4

= 4.25 ohms.

Current through entire circuit

$$= \frac{1.5}{4.25} = 0.353 \text{ amp.}$$

But suppose we divided cells up into two parallel rows of four cells in series, as in Fig. 177.

The e.m.f. of each series row would be

4×1.5, or 6 volts.

Since the two rows are in parallel, the total e.m.f. would be the e.m.f. of one row, or 6 volts. The internal resistance of each row would be

2×4, or 8 ohms.

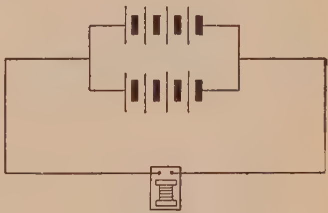


FIG. 177. The eight cells are arranged in two parallel rows of four cells in series.

But since the two rows are in parallel, the internal resistance of the whole combination of cells would be

$\frac{8}{2}$, or 4 ohms.

The resistance of the entire circuit would then be

4 + 4, or 8 ohms.

Current (through entire circuit)

$$= \frac{\text{voltage (across entire circuit)}}{\text{resistance (of entire circuit)}}$$

$$= \frac{6}{8} = 0.75 \text{ amp.}$$

This is greater than the 0.6-amp. current when the cells were all in series, and the 0.353-amp. current, when they were all in parallel.

The general rule for the arrangement of cells to give the greatest current through any given resistance is:

> **Arrange the cells so that the internal resistance of the whole combination of cells is as nearly as possible equal to the external resistance to be overcome.**

Cells are not usually arranged to give the greatest current but to supply requisite current and have the longest life. Thus it requires 5 cells in series to operate many spark coils. But very often 10 cells are used, that is, 2 parallel sets of 5 cells in series. This arrangement supplies practically the same current to the coil as the 5 cells alone, but each cell is called on for only half as much current and therefore lasts much longer.

To find the current which a certain combination of cells will force through a given resistance:

First:

Find the **total voltage** of the combination of cells.
Total voltage

$$= (\text{volts per cell}) \times (\text{number of cells in series}).$$

Second:

Find the **internal resistance** of the combination of cells.
Internal resistance

$$= \frac{(\text{resistance per cell}) \times (\text{number in series})}{\text{number of parallel rows}}.$$

Third:

Find the **total resistance** of the circuit.
Total resistance

$$= \text{external resistance} + \text{internal resistance}.$$

Fourth:

Find the **current** by Ohm's law.

$$\text{Total current} = \frac{\text{total voltage}}{\text{total resistance}}.$$

Example 7. In how many ways can 12 cells be arranged?

(1) 12 cells in series.
(2) 2 parallel sets of 6 cells in series.
(3) 3 parallel sets of 4 cells in series.
(4) 4 parallel sets of 3 cells in series.
(5) 6 parallel sets of 2 cells in series.
(6) 12 cells in parallel.

Example 8. Find the current which each arrangement of cells in the preceding example would send through an external resistance of 1.3 ohms. E.m.f. of each cell is 1.4 volts; internal resistance of each cell is 0.4 ohm.

(1) Twelve cells in series: Fig. 178.

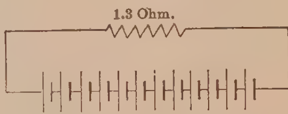


FIG. 178. Twelve cells in series.

First:

Total voltage = (volts per cell) $\times$ (number of cells in series)

$$= 1.4 \times 12$$
$$= 16.8 \text{ volts.}$$

Second:

$$\text{Internal resistance} = \frac{(\text{res. per cell}) \times (\text{number in series})}{\text{number of parallel rows}}$$
$$= \frac{0.4 \times 12}{1}$$
$$= 4.8 \text{ ohms.}$$

Third:

Total resistance = internal resistance + external resistance

$$= 4.8 + 1.3$$
$$= 6.1 \text{ ohms.}$$

Fourth:

$$\text{(Total) current} = \frac{\text{(total) voltage}}{\text{(total) resistance}}$$
$$= \frac{16.8}{6.1}$$
$$= 2.75 \text{ amperes.}$$

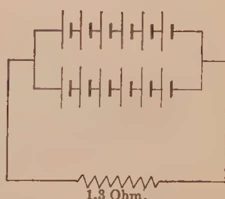


FIG. 179.
Two parallel rows of 6 cells in series.

(2) Two parallel sets of 6 cells in series: Fig. 179.

First:

Total voltage = (volts per cell) $\times$ (number of cells in series)

$$= 1.4 \times 6$$
$$= 8.4 \text{ volts.}$$

Second:

$$\text{Internal resistance} = \frac{(\text{res. per cell}) \times (\text{number in series})}{\text{number of parallel rows}}$$
$$= \frac{0.4 \times 6}{2}$$
$$= 1.2 \text{ ohms.}$$

Third:

$$\text{Total resistance} = \text{internal resistance} + \text{external resistance}$$
$$= 1.2 + 1.3$$
$$= 2.5 \text{ ohms.}$$

Fourth:

$$(\text{Total}) \text{ current} = \frac{(\text{total}) \text{ voltage}}{(\text{total}) \text{ resistance}}$$
$$= \frac{8.4}{2.5}$$
$$= 3.36 \text{ amperes.}$$

(3) Three parallel sets of 4 cells in series: Fig. 180.

First:

$$\text{Total voltage} = (\text{volts per cell}) \times (\text{number of cells in series})$$
$$= 1.4 \times 4$$
$$= 5.6 \text{ volts.}$$

Second:

$$\text{Internal resistance} = \frac{(\text{res. per cell}) \times (\text{number in series})}{\text{number of parallel rows}}$$
$$= \frac{0.4 \times 4}{3}$$
$$= 0.53 \text{ ohm.}$$

Third:

Total resistance = internal resistance + external resistance

$$= 0.53 + 1.3$$
$$= 1.83 \text{ ohms.}$$

Fourth:

$$(\text{Total}) \text{ current} = \frac{(\text{total}) \text{ voltage}}{(\text{total}) \text{ resistance}}$$
$$= \frac{5.6}{1.83}$$
$$= 3.06 \text{ amperes.}$$

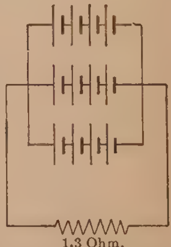


FIG. 180. Three parallel rows of 4 cells in series.

(4) Four parallel rows of 3 cells in series: Fig. 181.

First:

$$\text{Total voltage} = (\text{volts per cell}) \times (\text{number of cells in series})$$
$$= 1.4 \times 3$$
$$= 4.2 \text{ volts.}$$

Second:

$$\text{Internal resistance} = \frac{(\text{res. per cell}) \times (\text{number in series})}{\text{number of parallel rows}}$$
$$= \frac{0.4 \times 3}{4}$$
$$= 0.3 \text{ ohm.}$$

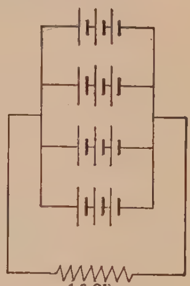


FIG. 181.
Four parallel rows of 3 cells in series.

Third:

$$\text{Total resistance} = \text{external resistance} + \text{internal resistance}$$
$$= 1.3 + 0.3$$
$$= 1.6 \text{ ohms.}$$

Fourth:

$$\text{(Total) current} = \frac{\text{(total) voltage}}{\text{(total) resistance}}$$
$$= \frac{4.2}{1.6}$$
$$= 2.63 \text{ amperes.}$$

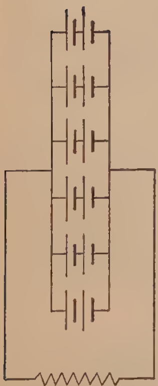


FIG. 182.
Six parallel rows of 2 cells in series.

(5) Six parallel rows of 2 cells in series: Fig. 182.

First:

Total voltage $= 2 \times 1.4 = 2.8$ volts.

Second:

$$\text{Internal resistance} = \frac{2 \times 0.4}{6} = 0.13 \text{ ohm.}$$

Third:

Total resistance $= 0.13 + 1.3 = 1.43$ ohms.

Fourth:

$$\text{Total current} = \frac{2.8}{1.43} = 1.96 \text{ amperes.}$$

(6) Twelve cells in parallel: Fig. 183.

First:

Total voltage $= 1.4$ volts.

Second:

$$\text{Internal resistance} = \frac{0.4 \times 1}{12} = 0.033 \text{ ohm.}$$

Third:

Total resistance = 0.033 + 1.3 = 1.333 ohms.

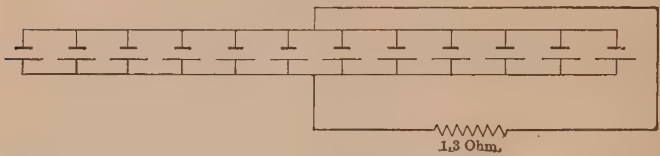


FIG. 183. Twelve cells in parallel.

Fourth:

$$\text{Total current} = \frac{1.4}{1.333} = 1.05 \text{ amperes.}$$

Note that the combination No. 2 (two parallel sets of 6 cells in series) gave the highest current, because in this case the internal resistance of the combination (1.2 ohms) was the most nearly equal to the external resistance (1.3 ohms).

Prob. 21. What is the greatest current that 20 cells, each of 1.4 volts e.m.f. and 0.5 ohm internal resistance, can send through a 12-ohm resistance? How would the cells be arranged?

Prob. 22. What is the greatest current that the cells of Prob. 21 can send through a resistance of 5 ohms? How would the cells be arranged?

Prob. 23. What is the greatest current that the cells in Prob. 21 can send through a 0.4-ohm resistance? How would the cells be arranged?

Prob. 24. What is the greatest current that the cells of Prob. 21 can send through a 40-ohm resistance and how would the cells be arranged?

96. Zinc as Fuel. The action of the fluid in a cell consumes the zinc by uniting with it and forming a chemical compound of little commercial value. Thus the zinc may be considered a fuel, just as is the coal which is consumed under a boiler by the action of the oxygen in the air, and

formed into ash. Since the cost of the energy obtained from using zinc in a battery is much greater than the cost of the energy obtained from coal burned under a boiler, the use of batteries is limited to places where a very small amount of power is required, as noted above.

97. Local Action. In a well-built cell, the chemical action which consumes the zinc goes on very slowly when the cell is not in use, so that a dry cell will last about a year if unused. The fact that there is any chemical action at all when the cell is not delivering current, is largely due to slight impurities, generally carbon, which are always present in zinc. The zinc, the carbon, and the fluid will form a little cell inside the larger cell, and set up an electric current. But since the speck of carbon is in direct contact with the zinc, the current will merely circulate around in the zinc plate. Thus zinc is consumed but no current is delivered to the outside circuit.

98. Polarization. If we allow the dry cell or the wet cell previously described to deliver a current for a few minutes through some electrical appliance, we note that the current does not remain at its first value but falls off very rapidly. The terminal voltage likewise falls off in the same manner. But if the cell is left on open circuit for a half hour or so, and again put on to the same electrical appliance, we find that it acts exactly as before. The starting current and voltage are almost, if not quite, as much as before and again they both decrease very rapidly, if the cell is left connected.

The reason for this behavior is that there is a gas formed at the carbon plate by the chemical action going on in the cell. This gas, called **hydrogen,** soon covers the plate to such an extent that not much of the fluid is in contact with the plate. Of course this gives less area through which the current may flow from the fluid to the plate,

and so increases the internal resistance of the cell. This collecting of hydrogen gas on the positive plate is called **polarization.**

If, however, the cell is now left disconnected a while, the hydrogen slowly disappears, being absorbed by chemicals placed near the carbon plate for this purpose.

> **The dry cells and wet cells thus described are called open-circuit batteries and should therefore be used on intermittent service only, such as bell ringing, spark coils, etc., to allow the positive plates to keep clear of hydrogen gas.**

Special wet cells are built, in which the chemicals act more quickly in absorbing the hydrogen. These are called **closed circuit cells** and, of course, are the kind to be used for a continuous current.

99. Test of a Dry Cell. If a dry cell does not give a reading of about 1.4 volts on open circuit when a voltmeter is put across its terminals, the cell is not fit for service.

However, many cells will show an e.m.f. of 1.4 volts on open circuit, when they are almost worthless on account of their high internal resistance, due to polarization, formation of crystals on the zinc, etc. In order to make sure that a dry cell is in good condition, it is always best to test it with an ammeter which has a scale reading of at least 25 amperes.

Put the ammeter directly across the terminals of the cell. As the resistance of the ammeter is extremely low, there is practically nothing to prevent a large current from flowing, except the internal resistance of the cell. If the cell is in good condition, this internal resistance is not very great, and a current of from 15 to 20 amperes will flow through the ammeter when connected across the terminals of a dry cell. A wet cell should give from 0.2 to 2.0 amperes under the same conditions.

100. Electroplating. Electrolysis. We have seen that whenever a current flows through the cells described above, some of the zinc plate is consumed by forming a chemical compound with the fluid. If, now, we apply a voltage to the cell from the outside and cause the current to flow in the opposite direction, the zinc will come out of the chemical composition and be deposited again on the zinc plate. This process is called **electrolysis.**

The amount of metal which one ampere will deposit from the solution in one hour is exactly the same amount which is taken from the plate by that solution, when a cell delivers a current of one ampere for one hour. It is called the **Electrochemical Equivalent** of the metal and varies with the different metals.

For zinc	the electrochemical	equivalent	is 0.0429	oz.
" copper	"	"	0.0418	"
" nickel	"	"	0.0386	"
" silver	"	"	0.1421	"

Example 9. A battery runs for 80 hours at an average rate of 2 amperes. How many ounces of zinc are consumed?

1 amp. for	1 hour	consumes		0.0429 oz.
2 " "	1 "	consume	$2 \times 0.0429 =$	0.0858 "
2 " "	80 hours	"	$80 \times 0.0858 =$	6.86 "

Prob. 25. How much zinc is consumed when a battery delivers 0.48 amp. for 245 hours?

Prob. 26. The zinc plate of a battery weighs 8 oz. How long will it last if the battery delivers an average current of 1.2 amperes for 5 hours every day?

Prob. 27. The zinc plate of a battery weighed 19.2 oz. before any current was taken from the cell. After a run of 200 hours the plate weighed 13.7 oz. What average current was taken from the cell, allowing for no local action?

The greatest use which is made of this fact, that the current will deposit metal from solutions, is in **Electroplating.** Thus, in Fig. 184, a piece of copper and a piece of iron are immersed in a solution of copper sulphate. If a current is now sent from the generator *G* through the

liquid from the copper to the iron, the copper will be separated from the solution of copper sulphate and deposited on the iron. The iron will then be copper plated. As fast as the copper goes out from the solution and is deposited upon the iron, more copper comes off the piece of copper and goes into the solution to replace that which goes to the iron from the solution.

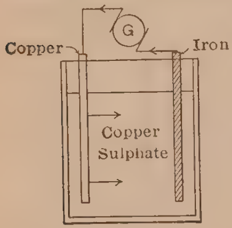


FIG. 184. The iron becomes copper plated when a current is sent through the cell as indicated.

If we desired to silver plate the iron, we would use a silver solution and a piece of silver in place of the copper plate. A nickel solution and a nickel strip would produce a nickel plate on the iron, etc. If by any chance the current were reversed, the plate would become plated with whatever metal was in the solution.

101. Electrotyping. The object of electrotyping is to reproduce the printers' set-up type, engravings, etc. A wax impression is first taken of the set-up type. Since wax is a non-conductor of electricity, the wax mold is now given a thin coating of graphite. The whole mold with its coating of graphite is immersed in copper sulphate together with a copper bar. An electric current is now sent through from the copper to the graphite. This causes copper to be deposited on the graphite just as it was deposited on the iron in the cell of the previous paragraph. The current is allowed to run long enough to deposit a plate of sufficient thickness to be handled safely. Then the wax mold is removed and the copper plate remaining is an exact reproduction of the type.

102. Refining of Metals. Since the metal, which is deposited on the negative plate, is remarkably pure, this method is often used to separate a metal from impurities.

The impure mass is made the positive plate. When an electric current is passed through the cell, the pure metal is gradually dissolved by the electrolyte and carried over to the negative plate. At the end of the process the negative plate is found to consist of very pure metal, since practically all the impurities remain at the positive plate.

For exact data and methods of procedure in the above processes, see "Electrochemical and Metallurgical Industry" and "Transactions of American Electrochemical Society."

Prob. 28. How long will it take to refine 150 lbs. copper if a current of 100 amperes can be used?

Prob. 29. An iron casting is to be copper plated and then nickel plated. The current in each case is to be 8 amperes. How long must it remain in each vat in order to have 14 oz. of each metal deposited on it?

Prob. 30. Two electroplating vats are arranged in series, one for nickel plating and the other for silver plating. If a current flowing through the vats deposits 1 oz. of silver in a given time, how much nickel is deposited at the same time?

103. Electrolytic Destruction of Metal Water Mains, etc. It is customary in electric railways to use the track as the return circuit. The rails, not being insulated from the ground, allow the current to leak into the ground and follow any low-resistance path it can find, such as a water or a gas main, back to generator, which of course, is also grounded.

Fig. 185 is a diagram of this action. Where the current enters the pipe at *A* no harm is done. But at the point *B* where the current leaves the pipe, generally near the generator station, there is all the action that takes place at the positive plate in an electroplating vat. The pipe, being in moist ground, is in contact with water containing

more or less salt, which causes it to act as an electrolyte. Thus, as the electric current leaves the pipe, there is a chemical action set up between the pipe and salt water, by which the iron of the pipe is eaten away in places, and

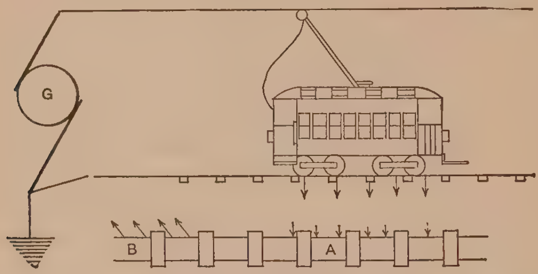


FIG. 185. An electric current is gradually eating away the pipe at *B*.

carried by the electric current to some outside substance, which for the instant is acting as the negative plate.

Heavy iron pipes have been eaten through in a short time by this action. Among the various precautions taken to avoid this destruction by electrolysis are the following: (1) The heavy bonding of the rails to procure a return of low resistance. (2) The use of a second trolley wire for the return. (3) Tapping a return line on to the water mains, to conduct back to the generator whatever current they may be carrying, without allowing it to flow through the water and produce electrolytic action.

Method No. 2 is the most efficient, but also the most expensive and is very seldom used.

104. Storage Batteries. In the ordinary primary cells, when the negative plate is nearly consumed, it is customary to replace it by another. If, instead of replacing the worn-out negative plate, we send a current from an outside source through the cell in the reverse direction, and deposit the metal back on the negative plate, the cell is then called

a **storage battery.** When such a cell is delivering current it is said to be **discharging**; when receiving current, it is said to be **charging.** A storage cell differs in no fundamental respect from a primary cell. Any primary cell could be used as a storage cell and have its negative plate restored by electrolysis as an ordinary storage battery does. It is not commercially economical, however, to do this in the case of any but a few cells, especially constructed for this purpose.

Remember that a storage cell **does not store electricity.** It stores nothing but chemical energy. In charging, electrical energy is transformed into chemical energy and stored in the cell; in discharging, this chemical energy is changed back again into electrical energy.

Of course there are losses in both transformations which prevent an efficiency of 100 per cent. For one thing, the terminal voltage **applied to** the cell on charge must be higher than that **supplied by** the cell on discharge at the same current rate, partly because, in each case, the internal resistance of the cell must be overcome.

In charging a cell, the current must be sent in **against** the e.m.f. and the resistance of the cell, while on discharge, part of the e.m.f. of the cell must be used to overcome this internal resistance in forcing a current to flow through it in the other direction; so that only **part of the e.m.f.** is available as terminal voltage. In this respect it is merely like any other electrical machine. Therefore an electric storage battery never gives out as much energy as is put into it; the best types generally give out about 75 per cent of the input.

105. Lead Cells. Two materials, lead and lead oxide, have been found to work well in a cell which can be used as a storage battery; lead for the negative plate and lead oxide for the positive plate. The liquid used is a half-and-half

mixture of sulphuric acid and water. The e.m.f. obtained is about 2.00 volts. The internal resistance is very low, about 0.0015 ohm, which allows the cell to deliver a very large current for its size. By putting enough cells in series, any desired voltage may be obtained.

Example 10. A lead cell has an e.m.f. of 2.00 volts and an internal resistance of 0.004 ohm. What will the terminal voltage be when discharging 20 amperes?

Volts to send 20 amp. through 0.004 ohm $= 0.004 \times 20 = 0.08$ volt.

Terminal volts on discharge = e.m.f. − volts to overcome internal resistance
$= 2.00 - 0.08$
$= 1.92$ volts.

Example 11. What voltage would have to be impressed across the storage cell of the above example in order to charge it at 20 amperes?

Volts to overcome internal resistance $= 0.004 \times 20 = 0.08$ volt.

Volts to charge = e.m.f. + volts to overcome internal resistance
$= 2.00 + 0.08$
$= 2.08$ volts.

Prob. 31. A lead storage cell has an e.m.f. of 2.04 volts and an internal resistance of 0.002 ohm. The normal charging current is 35 amp. What is its terminal voltage on charge?

Prob. 32. What is the terminal voltage of the cell in Prob. 31, when discharging at twice its normal rate?

Prob. 33. How many lead cells, each having an e.m.f. of 2 volts and an internal resistance of 0.005 ohm, will it take to light 10 incandescent lamps which are arranged in parallel? Each lamp requires 0.5 amp. at 108 volts.

Prob. 34. A battery of 15 lead cells is to be charged in series from a 110-volt line. Each cell has an e.m.f. of 2.10 volts and an internal resistance of 0.006 ohm. How many ohms resistance must be placed in series with cells so that the current shall not exceed 25 amperes?

Prob. 35. A set of 80 lead storage cells, each having 2.02 e.m.f. and 0.005 ohm internal resistance, is to be charged in two parallel sets of 40 cells in series. Each cell has a normal charging current of 30 amp. What must be the terminal voltage of the generator?

Prob. 36. If the cells in Prob. 35 are discharged in series at the normal rate, what will be the terminal voltage of the set?

Prob. 37. A set of 96 lead storage cells, each having 2.10 volts e.m.f. and 0.004 ohm internal resistance, is to be charged from a 110-volt line. If each cell is to take its normal current of 20 amperes, what would be the best arrangement of cells in order to have least power lost in a series resistance in the line?

Prob. 38. How could the cells in Prob. 37 be arranged in order to deliver 160 amperes and not exceed the normal current of each cell? At what terminal voltage would they deliver this current?

106. Rating of Storage Batteries. A storage battery is rated as to the number of **ampere-hours** it can deliver and the current at which it will deliver this number of ampere-hours. Thus a cell may have an 80-ampere-hour capacity for a 10-ampere rate. That is, it would maintain a current of 10 amperes for 8 hours.

Lead cells are usually rated on a steady discharge for 8 hours because they work best when discharged at such a rate that they need recharging only at the end of an 8-hour run. For instance, an ordinary lead cell may average a capacity of,

100 amp-hr. at 8-hr. rate (that is, at $12\frac{1}{2}$ amp.),
84 amp-hr. at 4-hr. rate (that is, at 21 amp.),
64 amp-hr. at 2-hr. rate (that is, at 32 amp.),
50 amp-hr. at 1-hr. rate (that is, at 50 amp.).

This means that this cell will deliver a current of

50	amperes for	1 hr.	$(50 \times 1) = 50$	amp-hr.	
32	"	" 2 "	$(32 \times 2) = 64$	"	"
21	"	" 4 "	$(21 \times 4) = 84$	"	"
$12\frac{1}{2}$	"	" 8 "	$(12\frac{1}{2} \times 8) = 100$	"	"

This shows conclusively that of the above rates of discharge, the 8-hr. rate, or $12\frac{1}{2}$ amperes, gives by far the greatest capacity to the cell.

In making up a combination of storage cells to deliver a certain current at a certain voltage, enough cells are arranged in series to produce the required voltage. Then enough parallel rows of these series sets are used so that each cell may deliver approximately its normal 8-hour current. The plate composed of the smaller number of "grids" is always the positive plate.

107. Care of Lead Storage Cells.

(1) Charge and discharge the cells, whenever possible, at about the 8-hour rate. Never discharge faster than twice the 1-hour rate, and never for more than 30 seconds at this rate.

(2) In charging, connect the positive terminal of the power supply to the positive terminal of the cell and regulate the current by a rheostat. Of course only direct current will charge a cell.

(3) Be sure that no impurity, such as any metal or acid, gets into the cell.

(4) Keep the fluid about 1.2 times as heavy as water. A hydrometer when floating in the cell should read about 1200.

(5) Never discharge a cell so far that its terminal voltage is less than 1.8 volts. (This voltage should be taken while the cell is discharging at the 8-hour rate).

(6) Never allow a cell to stand discharged. Recharge immediately.

(7) If the plates grow white, give the cell long-continued overcharges.

(8) When a cell is to remain unused for a long time, give it an hour or two of freshening charge about once or twice a month.

108. The Edison Storage Cell. The Edison storage cell consists of a positive plate of nickel oxide and a negative plate of spongy iron, in a solution of caustic potash.

The whole is contained in a steel can, which makes this cell much less liable to damage than the usual lead cell.

The voltage of the Edison cell at its normal discharge rate is only 1.2 volts as against 2.00 volts for the lead cell.

The Edison storage cell can be left charged or discharged for an indefinite time without being harmed. As seen by the previous paragraph, such treatment would ruin a lead cell.

The temperature of an Edison cell should be kept at about 70° F. An Edison cell is not injured by high temperatures, which cause lead cells to deteriorate rapidly. On the other hand, Edison cells lose nearly all their capacity at very low temperatures, which cause no trouble to lead cells. It must be said, however, that Edison cells operate successfully in cold climates, because the very act of taking current from them warms them up to an efficient temperature.

Edison cells are much lighter per watt-hour capacity than most lead cells.

SUMMARY OF CHAPTER VIII

AN ELECTRIC BATTERY transforms chemical energy into electrical energy. It consists of two unlike conductors called positive and negative plates immersed in a fluid which attacks one of the plates chemically. The voltage set up by this chemical action is called the electromotive force, commonly written e.m.f.

A common WET CELL consists of a negative plate of zinc, a positive plate of carbon, and a solution of sal ammoniac. Can be used only for intermittent service; E.m.f., about 1.5 volts; internal resistance, 1 to 4 ohms.

DRY CELLS consist of a positive plate of carbon surrounded by plaster paste containing sal ammoniac solution. These are placed in a zinc cup which forms the negative plate. Can be used for intermittent service only; E.m.f., about 1.5 volts; internal resistance, less than 0.1 ohm. Cheap and convenient.

The CURRENT which a cell is delivering depends upon the external and internal resistance of the circuit.

$$\text{Current} = \frac{\text{e.m.f.}}{(\text{external resistance}) + (\text{internal resistance})}.$$

The TERMINAL VOLTAGE of a cell when not delivering current equals its e.m.f. When a cell is delivering current the terminal voltage is the voltage across the external circuit only. Thus, it is that part of the e.m.f. which is not used to send the current through the inside of the cell. The greater the current, the lower the terminal voltage.

Terminal volts = e.m.f. − volts (across internal resistance).

Volts (across internal resistance) = internal resistance × current (through cell).

The SERIES ARRANGEMENT is best when the external resistance is high. With this arrangement,

$$(\text{Total})\ \text{current} = \frac{(\text{total})\ \text{e.m.f.}}{(\text{total})\ \text{resistance}}.$$

$$\text{Total e.m.f.} = \text{e.m.f. per cell} \times \text{number of cells}.$$

$$\text{Total resistance} = \text{external resistance} + \text{internal resistance}.$$

$$\text{Internal resistance} = (\text{resistance per cell}) \times (\text{number of cells}).$$

The PARALLEL ARRANGEMENT of cells is best when the external resistance is very low. With this arrangement,

$$\text{Total current} = \frac{\text{total e.m.f.}}{\text{total resistance}}.$$

$$\text{Total e.m.f.} = \text{e.m.f. of one cell.}$$

$$\text{Total resistance} = \text{internal resistance} + \text{external resistance.}$$

$$\text{Int. resistance} = \frac{\text{resistance per cell}}{\text{number of cells}}.$$

The ARRANGEMENT FOR GREATEST CURRENT is such a combination of series and parallel, that the internal resistance of the combination of cells equals the external resistance of the circuit.

The current is found by the usual equation,

$$\text{(Total) current} = \frac{\text{(total) e.m.f.}}{\text{(total) resistance}}.$$

$$\text{Total e.m.f.} = \text{e.m.f. per cell} \times \text{number of cells in series.}$$

$$\text{Total resistance} = \text{internal resistance} + \text{external resistance.}$$

$$\text{Internal resistance} = \frac{\text{resistance per cell} \times \text{number in series}}{\text{number of parallel sets}}.$$

The ZINC IS CONSUMED AS A FUEL in batteries. Its high cost prevents extensive use of batteries as a source of electric power.

LOCAL ACTION is set up when there are any impurities on the surface of the zinc. This impurity (together with the fluid and zinc) sets up a small local current which consumes the zinc, but produces no terminal voltage.

POLARIZATION is the forming of bubbles of hydrogen gas on the positive plate, which increases the resistance. They are removed by chemicals which are put into the solution for that purpose. But these chemicals act so slowly that if the wet and dry cells in general use are not allowed to rest after every very short run, they become so badly polarized that the terminal voltage is almost zero.

TEST a cell by placing a 25-ampere ammeter directly across the terminals of the cell. A dry cell in good condition should read from 15 to 25 amperes. A wet cell in good condition should read from 0.2 to 2 amperes.

ELECTROLYSIS is the opposite of the battery effect. When a current is sent through a metal salt solution, it takes the metal

out of solution and deposits it on the negative plate. The weight of metal deposited is always the same per ampere-hour for the same solution. By sending a current through copper sulphate, the copper is deposited on the negative plate, which may consist of wax prints of set-up type, etc. Silver plating is done in the same way by using a solution of silver nitrate.

ELECTROLYTIC DAMAGE TO WATER MAINS takes place whenever the current of electricity, which has been flowing along it, leaves the pipe to go to some other conductor.

STORAGE BATTERIES make use of electrolysis by the possibility of sending a current in the reverse direction through a cell. This redeposits on the negative plate the metal which has been consumed by the fluid. Common types have spongy lead for the negative plate, lead oxide for the positive plate, and dilute sulphuric acid as the fluid. Their e.m.f. is about 2.20 volts; internal resistance, very low.

STORAGE BATTERIES ARE RATED as to the number of ampere-hours they will give out, at a given current. They are usually rated on the current they can maintain for 8 hours. The capacity grows rapidly less as the current is increased, being about $\frac{1}{2}$ as great if allowed to discharge in 1 hour.

EDISON STORAGE BATTERY consists of a negative plate of spongy iron, a positive plate of nickel oxide; fluid, caustic potash. E.m.f. about 1.2 volts; internal resistance, a little larger than that of lead cells. Light and rugged. Efficient temperature range is limited. Can remain charged or discharged indefinitely without harm.

FOR CARE OF LEAD STORAGE CELLS. See page 220.

PROBLEMS ON CHAPTER VIII

Prob. 39. What current flows when 5 cells are connected in series to a circuit having 24 ohms resistance? Each cell has an e.m.f. of 1.48 volts and an internal resistance of 0.4 ohm.

Prob. 40. A telegraph line consists of 5000 ft. of No. 8, B. & S. gauge iron wire. There are two relays on the line, each having 150 ohms resistance. How many cells will be required to send 0.25 ampere through the above line, and how would you arrange them? Each cell has 1.3 volts e.m.f. and 2 ohms internal resistance.

Prob. 41. Suppose that 56 storage cells, each having an e.m.f. of 2.1 volts and an internal resistance of 0.015 ohm, are to be used to light 12 incandescent lamps of 200 ohms each, arranged in parallel.

(*a*) What current flows through the main line?
(*b*) What current flows through each lamp?
(Neglect resistance of line wires.)

Prob. 42. If the line wires of Prob. 41 have a total resistance of 0.6 ohm, what current will the cells deliver?

Prob. 43. What is the terminal voltage of the cells:
(*a*) In Prob. 41?
(*b*) In Prob. 42?

Prob. 44. What would be the voltage at the terminals of the lamps in Prob. 42?

Prob. 45. What power is lost in the line in Prob. 42?

Prob. 46. What power is lost in the cells in Prob. 42?

Prob. 47. The terminal voltage of a certain cell is 1.2 volts when delivering 2.2 amperes. When delivering 3 amperes the terminal voltage is 1 volt. What is the internal resistance of the cell?

Prob. 48. How many cells, each having an e.m.f. of 1.08 volts and an internal resistance of 2 ohms, would be required to operate a telegraph line having a total resistance of 500 ohms? A current of 0.25 amp. is generally used in a telegraph line.

Prob. 49. A battery of 6 dry cells in series is used to send a current through a resistance of 0.08 ohm. Each cell has an e.m.f. of 1.5 volts and an internal resistance of 0.1 ohm. How much current flows?

Prob. 50. If the cells in Prob. 49 were arranged in parallel, how much current would flow through the external circuit?

Prob. 51. If the cells in Prob. 49 were arranged in 2 parallel sets of 3 cells in series, how much current would flow through the external circuit?

Prob. 52. How much current would flow through each cell:
(*a*) In Prob. 49?
(*b*) In Prob. 50?
(*c*) In Prob. 51?

Prob. 53. What current would flow through the external circuit if the cells in Prob. 49 were arranged in 3 parallel sets of 2 cells in series?

Prob. 54. The normal current of each storage cell in a certain battery is 5 amperes, its internal resistance is 0.002 ohm, and e.m.f. is 2.15 volts. The cells are required to light 40 incandescent lamps each taking $\frac{1}{2}$ ampere at 112 volts. Consider the line wires of negligible resistance. How many cells are necessary and how should they be arranged?

Prob. 55. If a line wire of 0.2 ohm were used in Prob. 54, how many cells would be required and how should they be arranged?

Prob. 56. What would be the terminal voltage of the set of cells used in Prob. 55?

Prob. 57. A generator delivers 120 amperes at 115 volts. A battery of storage cells, whose normal discharge rate is 30 amperes, is kept as reserve, in case of accident to the generator. If the battery were to be large enough to take the place of the generator for 1 hour, how many cells must be used, and how should they be arranged? Each cell has an e.m.f. of 2.10 volts and an internal resistance of 0.0015 ohm.

Prob. 58. If the cells of Prob. 57 were charged as connected in Prob. 57, what charging voltage would be necessary?

Prob. 59. What charging voltage would be necessary to charge the battery as connected in Prob. 54?

Prob. 60. A Christmas tree is to be lighted by 16 miniature incandescent lamps each taking 0.8 amp. at 6 volts. How many storage cells would you use to light the tree for one hour? Each cell has an e.m.f. of 2.10 volts, an internal resistance of 0.008 ohm, and a normal current rate of $\frac{5}{8}$ ampere. Assume the short copper line wire to have a resistance of 0.02 ohm. State how you would arrange the lamps and the cells.

Prob. 61. What size line wire should be used in Prob. 60?

Prob. 62. If the lamps of Prob. 60 were to be lighted from a 110-volt circuit:

(*a*) How would you arrange the lamps?

(*b*) What resistance would it be necessary to place in series with the lamps?

Prob. 63. What size wire would be used as lead wires in Prob. 62?

CHAPTER IX

WIRING DIAGRAMS

ELECTRIC BELLS AND ANNUNCIATORS

109. Single Stroke. The simplest single-stroke bell is constructed as in Fig. 186. When the button P is pushed, the battery sends a current through the coils of the electro-

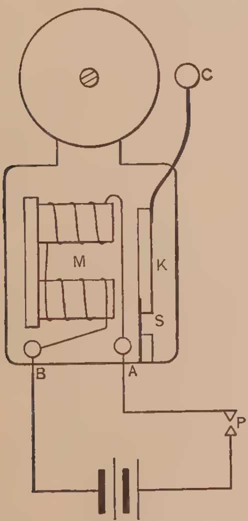


FIG. 186. Single-stroke electric bell.

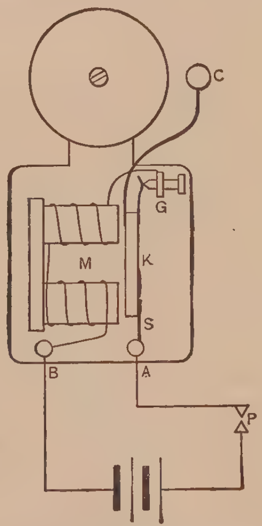


FIG. 187. Vibrating-stroke bell. Circuit-breaking type.

magnet M. The magnetic attraction then draws the armature K over toward the magnet, the clapper C hitting the bell. As long as the points at P are in contact, the armature K remains against the magnet. But on releasing the button, the contact points separate, and the circuit

through the electromagnet is broken. This releases the armature *K*, which is pulled back into place by the spring *S*.

110. Vibrating Stroke. Circuit-breaking Type. The same form of bell with vibrating stroke is shown in Fig. 187. When the button *P* is pushed, the circuit is closed and a current flows through the coils on the electromagnet *M*. This causes the armature *K* to be drawn toward the magnet, the clapper *C* hitting the bell. But as the armature is drawn toward *M*, it moves away from the set screw *G*. This causes the circuit to be broken at that point, so the magnet *M* loses its magnetizing force and no longer attracts the armature *K*. The spring *S* then causes *K* to fly back and again make contact at *G*. The current once more flows through the magnet and again *K* is pulled over, and the bell struck. This vibrating action takes place very rapidly, as long as the button *P* is held down. Bells so constructed are very cheap and are in common use, battery cells being used as a source of power.

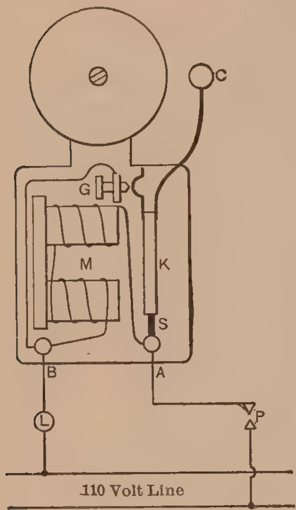


FIG. 188. Vibrating-stroke bell. Short-circuit type.

111. Short-circuit Type. But when the electric lighting circuit is used to ring the bells the points at *G* soon become fouled on account of the excessive sparking which takes place every time the circuit is opened at this point. To avoid this, two other types of vibrating-stroke bells are in common use: the **short-circuit bell**, Fig. 188, and the **differential bell**, Fig. 189.

Note in the case of the short-circuit or shunt bell that when the circuit is closed at *P*, the current goes through the windings on the magnet *M* and draws the armature *K* over. This makes a contact at *G*, which shunts the current around through the short circuit thus made, and almost no current is left flowing through the coils on *M*. This

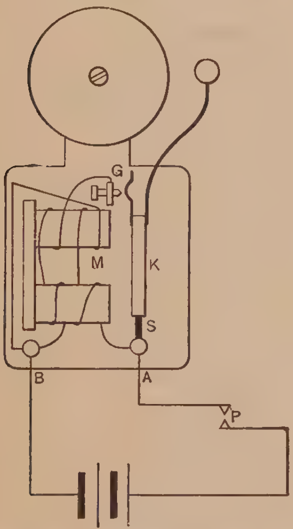


FIG. 189. Vibrating-stroke bell. Differential type.

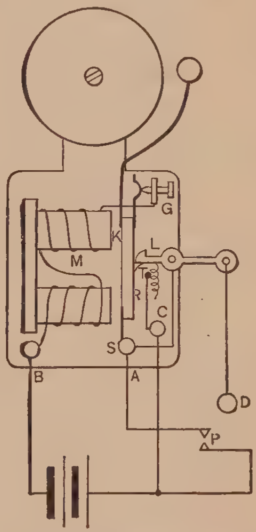


FIG. 190. Continuous-ringing bell.

weakens the magnet so much that the armature *K* is brought back by the spring *S*: thus a vibrating stroke is produced.

Note that a lamp *L* is connected in series with the bell when it is used on a 110-volt line. If it were not for this lamp, the coils on the magnet would have the same current flowing through them, whether there was a contact at *G* or not, because the magnet coils would always be directly

across the 110-volt line. The 110 volts would always force the same current through them, regardless of whether or not there was a short circuit around them.

When the circuit is closed at *P* the lamp allows just a certain amount of current to enter the bell. When all of this current is allowed to go through the coils on the magnet, the armature is drawn over. But when the greater part of this current is allowed to go through the short-circuit shunt, as explained above, the magnet becomes very weak.

This type of bell would soon run a battery down, hence it is rarely used except on a lighting circuit, with a lamp or some other resistance in series with it.

112. The Differential Type of Bell. The differential bell of Fig. 189 will work either on a battery or on the lighting circuit with a lamp in series with the bell.

When *P* is pressed, the current goes through the winding near the pole tips of the magnet *M*. This draws over the armature, making contact at *G*, so that a current also goes through the magnet winding shown near the yoke. But note that the currents in the two coils set up magnetic fields which oppose each other. The result, if the coils are properly arranged, is no magnetic force at all. The armature is then drawn back by the spring *S*, which breaks the current in the coils near the yoke. Then the current in the other coils again magnetizes *M* and draws the armature over, thus producing a vibrating stroke.

113. Continuous-ringing Bell. In Fig. 190, the bell has an added terminal *C* which is connected directly to the battery. When the circuit is closed at *P* the armature is drawn toward the magnet. This releases the lever *L* from the detent *T*, and a small spring pulls it into contact with the post *R*, which is connected to *C*. Thus a circuit is at once completed from the battery to *A* through the terminal *C*, the post *R* and the lever *L*, which is connected directly

to terminal A; hence the bell will continue to ring, even after the button P is released, until the lever L is reset by pulling the cord D.

Prob. 1. Draw the diagram of a bell with 3 terminals which can be used either as a single-stroke or as a vibrating-stroke bell. Show the battery connections.

Prob. 2. Make a diagram of a bell with continuous-ringing attachment, which can be used on the lighting circuit. Show the connections to the lighting circuit.

114. Buzzers. A buzzer is constructed like any of the bells described above. The clapper and bell are left off and the noise is made by the vibrating armature. A

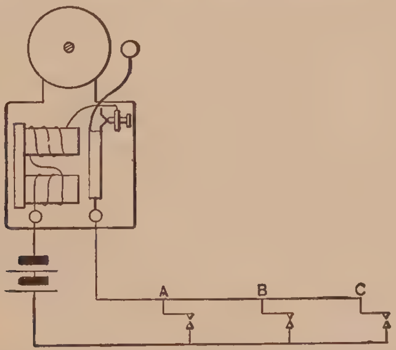


FIG. 191. A bell arranged to be rung from any of the three stations A, B or C.

master buzzer is often used to operate a set of cheap bells. These bells must be of the single-stroke type arranged in series. The buzzer merely opens and closes the circuit and causes the bells to act as vibrating-stroke bells. This is a very handy arrangement, since the contact points on the buzzer are the only ones in the circuit to get out of order, and therefore the system is more easily kept in good condition.

Prob. 3. Draw the diagram of a buzzer operating 3 bells on a battery line. Include the complete electrical circuit.

Prob. 4. Draw a diagram of a buzzer to operate on a 110-volt line, ringing two bells. Put in the complete electrical circuit.

Example 1. How can a circuit be arranged so that a bell can be rung from any of three places?

The bell in Fig. 191 can be rung from any of the stations *A*, *B* or *C*. Either main line wire may consist of a "ground," such as a gas pipe, water pipe, etc.

Prob. 5. Two or more circuit-breaking bells will not work well in series. Draw a diagram showing how a single-stroke bell can be used in series with a circuit-breaking bell.

Prob. 6. Draw a diagram showing how the combination bell in Prob. 1 can be rung from two stations; from one as a single stroke, from the other as a vibrating stroke.

115. Electric Door Opener. In apartment houses it is desirable to be able from each apartment to release the catch on the hall door. This is very easily accomplished by using the mechanism of a single-stroke bell, leaving the clapper and bell off. The movement of the armature, when the circuit is closed by pushing a button in any of the apartments, releases a special lock and allows the door to be pushed open.

Prob. 7. Show the wiring diagram of an arrangement for ringing a bell in the apartment by a push button at the hall door, and for operating the hall-door opener from a push button in the apartment. Both are to use the same battery.

Prob. 8. Show the connections for wiring four bells and one battery so that one bell may be rung from any one of three stations, while the other three bells may be rung from a fourth station.

Prob. 9. Show the diagram for wiring the following:

Bell No. 1, to be rung from the front door push button.
Bell No. 2, " " " " " rear " " "
Buzzer, " " " " " dining room " "

All bells are to ring by the same set of batteries.

Prob. 10. Show by a diagram a set of three bells which may be operated by one push button, and which may use current either from a set of cells or from the lighting circuit.

Prob. 11. Bells are often rung by two sets of storage batteries, one set being charged from the lighting circuit through lamp resistances, while the other is in service. Show a diagram for accomplishing this in such a way that the bell wiring is never connected to the lighting circuit, and therefore poorer insulation can be used on the bell circuit.

116. Annunciators. When several rooms are connected to a single bell, it is usual to put an annunciator in each circuit in order to tell from which place the call comes.

Fig. 192(*a*) shows the appearance of the indicator when it is idle. When it is tripped, a white ball shows at the window, as in Fig. 192(*b*). The mechanism is explained by Fig. 192(*c*). The white surface is made of non-mag-

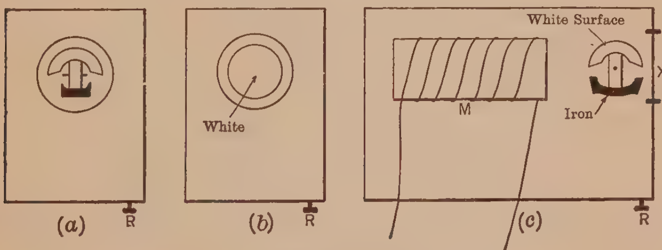


FIG. 192. An electric annunciator.

netic material, but is joined to a piece of iron *D* of crescent shape, and the whole is pivoted near the center. When a current goes through the coils of the magnet *M*, it attracts the crescent-shaped iron, and in drawing it nearer, turns the white surface out toward the window (x). The indicator is usually arranged to remain in this position, when once tripped, until it is released by the attendant who pushes the button *R*, which shoves the indicator back to the "idle" position.

Another very common type of annunciator has small arrows instead of the white surface; one arrow for each station. The "idle" position is with the arrow horizontal. When the bell is rung, the arrow indicating the calling station swings to a vertical position. It is brought back to the horizontal by pushing or pulling on a lever.

By means of an annunciator box placed near the bell in Fig. 193 it is possible to tell from which of the three stations a call is coming.

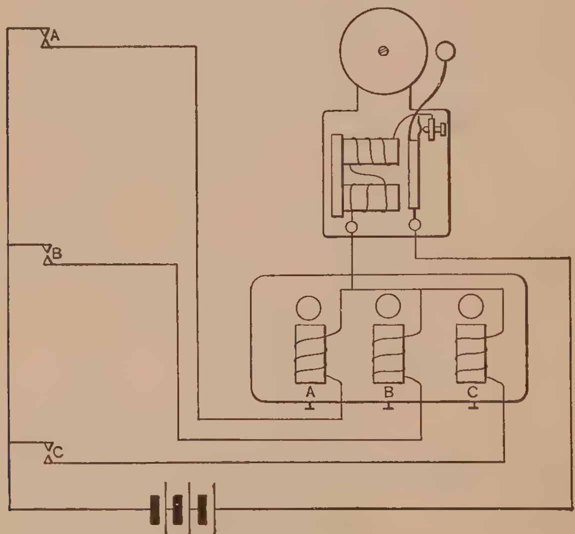


FIG. 193. A single bell with annunciator which indicates by which of the three stations *A*, *B* and *C*, the bell is rung.

In Fig. 194 is shown a return call annunciator system used in many hotels, where it is necessary for the guest to be able to ring up the desk, and for the desk to ring up the guest.

Prob. 12. Several patented systems are on the market which form very compact devices for accomplishing the results obtained by Fig. 194. They usually make use of 3-way push buttons in place of the simple 2-way button of the illustrations. Draw a diagram showing typical wiring of one of these systems, using a 3-way push button or strap key, as shown in Fig. 195.

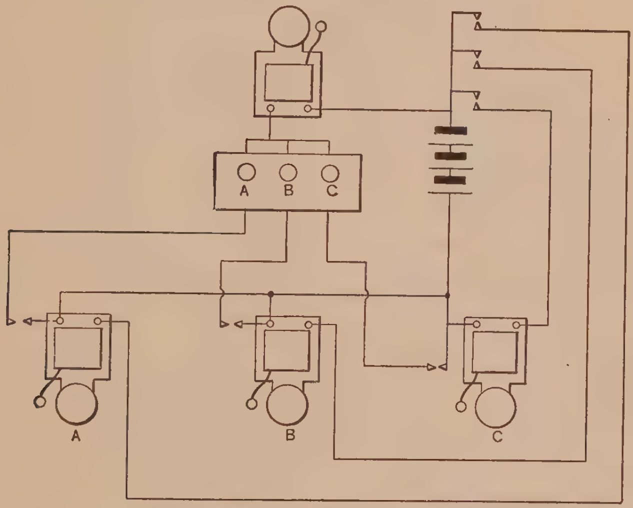


FIG. 194. A return-call annunciator system. The bell at the top can be rung from any of the three stations below at *A*, *B* and *C*.

117. Fire-alarm Systems. There are many systems for sending in fire alarms. They are all, however, arranged to sound continuous-ringing gongs at several places in the building, and most of them have an annunciator attachment showing the place from which the alarm was sent in. For simplicity, a system having but three gongs and three sending stations is shown in Fig. 196.

FIG. 195. A three-way push button, or strap key.

Note that wherever any one of the three switches A, B and C is thrown, it rings all three bells A', B' and C', and the annunciators at the bells indicate which switch is thrown. These switches can be thrown by hand or auto-

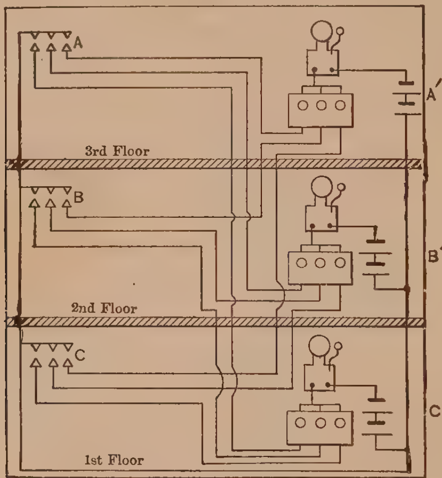


FIG. 196. Fire-alarm system. Three gongs and three stations.

matically by means of a thermostat as in Fig. 197. The thermostat operates as follows: A strip of hard rubber is riveted to a steel spring which is fastened firmly to the support P. When heated, both steel and rubber expand, but rubber expands much more than steel. This causes the spring to bend or buckle and make an electrical contact at G. A current now flows through the relay and draws over the armature which releases the detent T, and allows the spring S to draw down the switch and close the circuit.

Special thermostat metal, consisting of a strip of brass brazed to a strip of steel, is often used, instead of the steel-rubber combination.

Many other modifications of this system are in use, which make the entire action more certain, but they all work on the general principles illustrated.

Prob. 13. Fire-alarm systems sometimes are arranged so that a current is maintained throughout a series circuit of fusible plugs located in different parts of the building. When any plug is fused, it opens the circuit, allowing the switch arm to drop and close the bell-ringing circuit. Of course, there can be no annunciator used where all the stations are in series. Make a diagram of such a system.

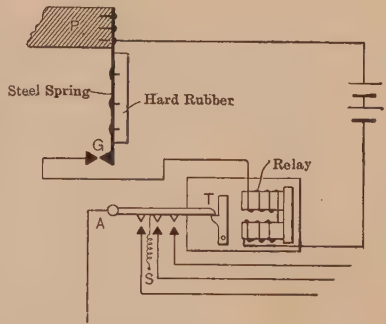


FIG. 197. A thermostat arranged for automatically sending in a fire alarm.

118. Burglar Alarms. In order that the system may not be put out of order by the cutting of the wires, burglar alarms are generally of the closed-circuit type. A simple scheme of this kind is shown in Fig. 198. The battery *B* causes a current to flow through a circuit in series with the coils on the magnet *M* in the bell. This keeps the armature drawn over, leaving a break at *G*, so that battery *A* is not sending a current through the bell. But, as soon as the circuit containing battery *B* is broken, the armature springs back and is kept vibrating by battery *A*. The devices marked *C* and located at all windows, doors, skylights, etc., are often constructed on some modification of the device shown in Fig. 199 and are called "traps."

The switch *A* is held on the contact point *C* by the string *T* which pulls against the spring *S*. This string is fastened to the window or door. The contact is so delicate that if the string is pulled very slightly, the switch is moved from the contact point *C* and the main circuit is opened. The

bell is thus set ringing, as explained above. If, on the other hand, the string is cut or slackened the least bit, the spring S pulls the switch away from the contact point in the other direction and opens the circuit.

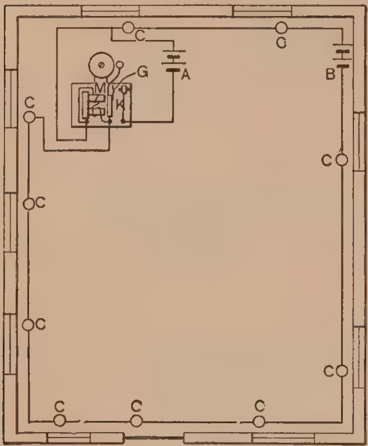


FIG. 198. Closed-circuit burglar alarm.

In an open-circuit system, a modification of this device is used as shown in Fig. 200. The slightest change in tension on the string T now closes the circuit, either on one button or the other.

Many other "traps" are made, which can be built into the window sash or the door jamb or laid under the mat or the carpet. In many cases, each window and door has a separate circuit passing through an annunciator. Before setting the alarm for the night, the bell can be thrown out of the circuit and the annunciator used to locate any window or door which may not have been closed or locked.

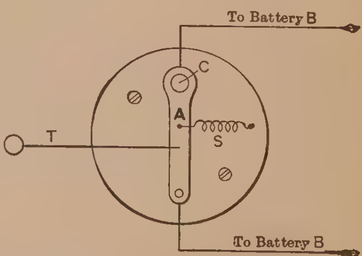


FIG. 199. Closed-circuit "trap."

Prob. 14. Make a diagram of a simple burglar-alarm system using the device of Fig. 200 for a "trap."

119. Electric Devices for Lighting the Gas. In lighting gas by an electric current, it is necessary to produce a spark in the gas as it flows from the burner. In order to

obtain this spark by means of a battery current, a spark coil is inserted into the circuit as shown in Fig. 201. This coil consists of a core of soft iron, generally in the form of iron wires, on which is wound a large number of turns of the insulated copper wire of the electric circuit. The end view of Fig. 201(*b*) shows the ends of the iron wire forming the core, and the copper wire wound around this core but insulated from it. As the switch *P* is closed, a current flows through the circuit and makes a strong magnet of the coil. When the switch *P* is opened, an electric spark jumps across the gap. It is necessary then merely to open an electric circuit of this kind at such a place that the gap occurs in the stream of gas coming from a burner. In Fig. 202, note that one side of the line is grounded by being soldered to the gas pipe, which forms the return line. The other side of the line goes through the spark coil *C* and is wrapped around the pipe, though carefully insulated from it, and ends in the point *A*. The other side of the line

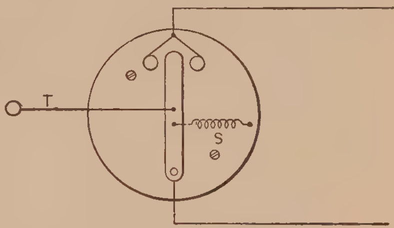


FIG. 200. Open-circuit "trap."

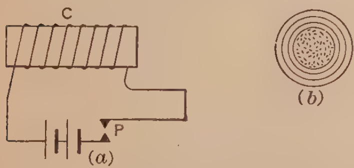


FIG. 201. Diagram of a spark coil.

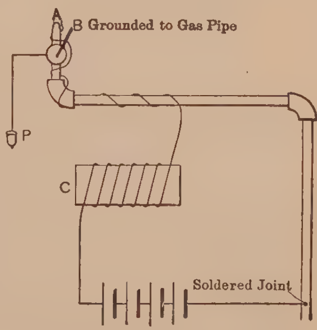


FIG. 202. Simple gas-lighting device, using a spark coil.

ends in the point B. When the cord P is pulled, it opens the gas cock and brings B into contact with A, and then immediately breaks the contact, causing a spark to pass between the points A and B. This spark lights the gas. Any number of these jets can be arranged in parallel, by running a wire from each jet to the coil, the pipe furnishing a common return.

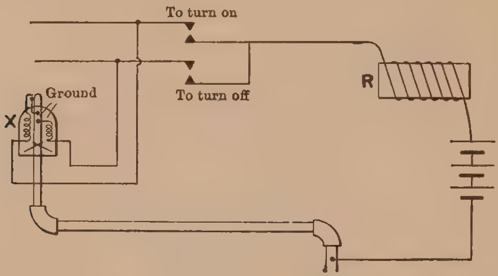


FIG. 203. Automatic gas-lighting system.

A device for lighting and extinguishing the gas from push buttons located at convenient points in the wall is shown in Fig. 203 and 204. Note that it requires two buttons and two wires to each burner, the pipe affording the common return path. When the button labeled "on" is pressed, the current flows from the battery, through the spark coil R, to the coil (x) at the burner, then up to the point B, which is in contact with the point A. From here it passes through the rod C, Fig. 204, to gas pipe and back to the battery. As the current goes through the coil (x) it pulls up the armature F_2, Fig. 204. A spur attached to this armature engages the teeth on D and turns on the gas. At the same time the armature pushes up the rod C which opens the circuit between the points A and B. A spark then jumps across this gap and lights the gas, which has been turned on as noted.

When the circuit is opened, as explained above, between the points A and B, the current ceases to flow through the coil (x). This allows the armature F_2 to drop, and the spring S brings the point A back into contact with B. This causes the armature to fly up again, opening the gas

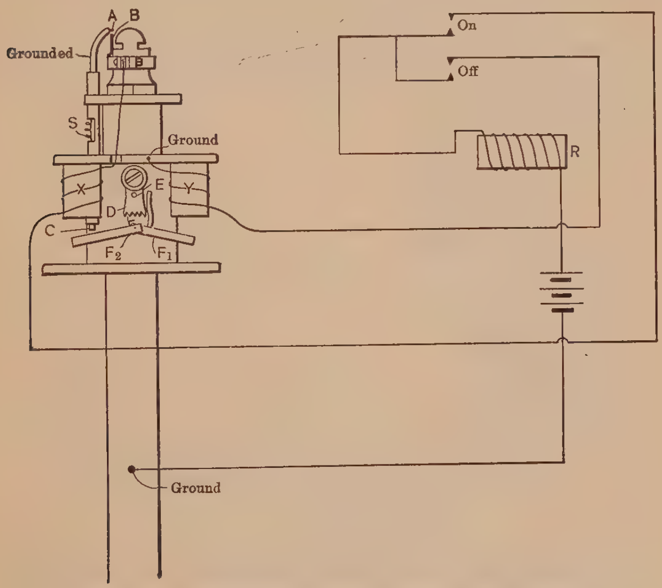


Fig. 204. Details of automatic gas-lighting system.

valve a little more and sending another spark across the gap between A and B. In fact the operations take place very rapidly, a continuous flow of sparks taking place across the gap as long as the "on" button is held down. This makes it almost certain that the gas is lighted as soon as it is turned on by the motion of the armature.

To turn off the gas, the button labeled "off" is pressed. The current from the battery now flows through the coil

(y) at the burner, and goes directly through the pipe back to the battery. As the current passes through the coil (y), the armature F_1 is pulled up. A spur on this armature engages the pin E and closes the valve, shutting off the gas. Since the armature F_1 does not break the circuit when it comes up, it remains up as long as the "off" button is pressed, and thus makes but a single click. The armature F_2 makes a buzzing sound when the "on" button is pressed, on account of the rapid opening and closing of the circuit.

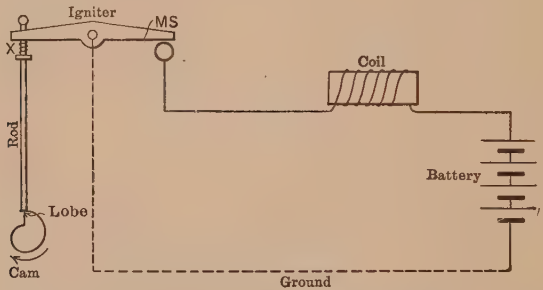


FIG. 205. Make-and-break system of gas-engine ignition, using batteries and spark coil.

At any number of places, duplicate "on" and "off" buttons may be located. These buttons will always be connected in parallel with the first set.

120. Gas-engine Ignition. Make-and-break System. We have seen that when an electric circuit containing a coil with soft iron core is broken, a spark jumps across the gap. Use of this is made in exploding the gas in the cylinder of a gas engine (see Fig. 205). As the engine shaft revolves, it turns the cam in the direction marked. This gradually pushes up the rod so that the points M and S of the igniter touch each other and a current flows in the

circuit thus made. When the "lobe" of the cam passes by the rod, the spring *S* suddenly pulls the rod down and separates the points *M* and *S*, and a spark jumps across the gap. These two points are situated inside of the cylinder of the gas engine. The break is so timed that the spark comes when the cylinder is full of compressed gas which is thus exploded, and furnishes the force to drive the piston. This is called the **make-and-break** system of ignition.

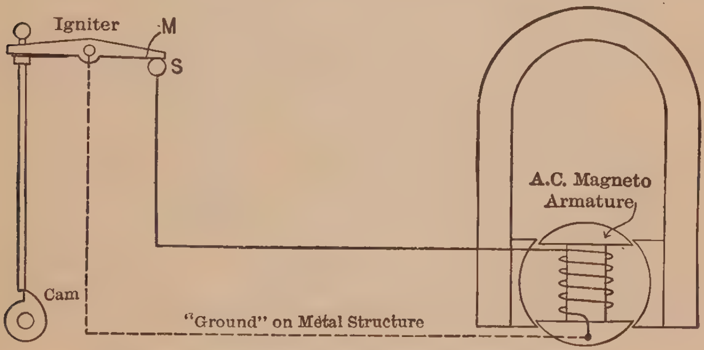


FIG. 206. Make-and-break system using magneto.

Fig. 206 shows the coil and battery replaced by a magneto generator, which is driven by the engine. Such an arrangement is usually started on a battery, as shown in the previous figure. The battery is cut out when the engine gets up speed.

121. Jump-spark System. It has been found that if we wind two coils of wire on a soft iron core and "make" and "break" a current in one of these coils (called the **primary coil**), a voltage is set up across the terminals of the other coil (called the **secondary coil**). If we make the number of turns of wire in the secondary coil many times as great as the number of turns used in the primary coil,

the voltage thus induced across the secondary will be many times that across the primary.

Use is made of this fact for gas-engine ignition by winding two coils on a core as on *M* in Fig. 207.

The primary circuit consists of the primary coil, battery, timer, and a make-and-break device *V* similar to that in an electric bell. The secondary circuit consists of the secondary coil *S*, the battery and the **spark plug** (*x*).

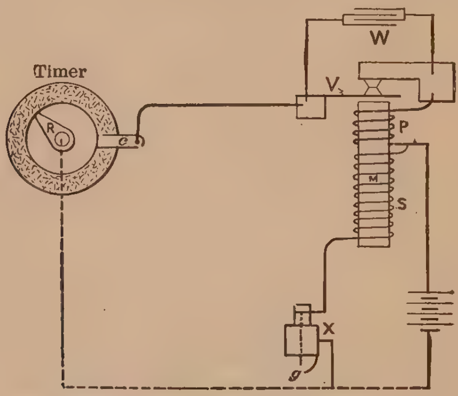


FIG. 207. Jump-spark system of gas-engine ignition.

When the **rotor** *R* of the **timer** strikes the contact piece *C*, the current flows from the battery, through the primary coil *P* and makes the iron core *M* a magnet. This attracts the armature *V*, called a **vibrator** or **trembler.** This opens the primary circuit, as in a vibrating bell, and immediately a high voltage is set up across the terminals of the secondary coil *S* which causes a spark to jump across the gap (*g*) in

Footnote. Figures 206 and 207, illustrating gas-engine ignition, are taken from "Electric Ignition" by Forrest R. Jones. The student is referred to this excellent work for full information on the details of the various systems in use.

the spark plug. The spark plug is located within the cylinder and explodes the gas, as explained above.

The vibrator *V* is a much more delicate device than the vibrator in a bell, and works much more rapidly.

The device marked (*w*) is a condenser and is added merely to decrease the sparking at the vibrator, when the primary circuit is broken.

122. The Telegraph. The following paragraphs on the telegraph and the telephone are not intended to serve as wiring instructions for installing these devices, but merely as an explanation of the principles upon which they operate.

In Fig. 208 is shown a telegraph system with two stations. A large number of stations may be arranged in

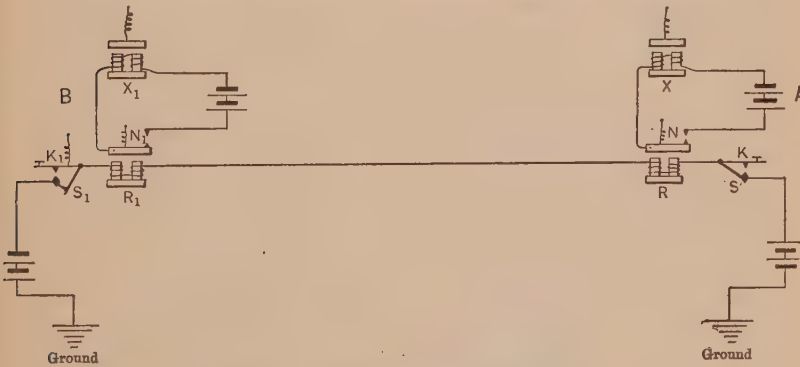


FIG. 208. Diagram of a telegraph line.

series on a single line. Note that there is a local circuit at each station and a main circuit between stations. The main circuit is closed when the line is not in use. This holds down the armatures *N* and N_1 of the local circuits. The batteries on the main line must be of the closed-circuit type to prevent their running down.

Suppose station *A* wishes to send a message to *B*. The short-circuiting switch *S* is opened and the main line is

thus opened. This releases the armature on the relays R and R_1, because the main current is broken. These relays are similar to the magnet and vibrator in an electric bell, but they are much more delicate so that a minute current will operate them. They are used merely to open and close the local circuits. When any key, for example the one at A, is up, the spring pulls up the released relay armatures N and N_1 and closes the local circuits so that the sounders (x) and (x_1) attract their armatures, making the peculiar clicking sound which is heard in a telegraph office. Now when A presses down his key K again, the armatures of both relays are drawn down, opening the local circuits. The springs on the armatures of the sounders (x) and (x_1) now draw these up and produce another click. Every time the key K is released or pressed down, all the relays on the line move and actuate the armatures of the sounders in all the local circuits. At most stations, cut-out switches are arranged in the local circuits so that only the sounder of the station called is allowed to click. The so-called "dots and dashes" are produced by varying the length of time between clicks; the time for the dashes being slightly longer than that for the "dots." When the line is not being used all instruments are left in service in order to receive the "calling signal." The main line usually consists of a galvanized iron wire either 165 mils or 203 mils in diameter. The ground forms the "return."

Prob. 15. A standard telegraph sounder has 5 ohms resistance. The local circuit is wired with 120 ft. of No. 22, B. & S., copper wire. The local battery cell has an e.m.f. of 1.08 volts and an internal resistance of 3 ohms. What current passes through the local circuit every time the sounder acts?

Prob. 16. A 15-mile telegraph line using the ground for a return has 3 relays of 20 ohms each connected in it. The line is operated by 10 cells in series, each having an e.m.f. of 1.07 volts and 2.8 ohms

internal resistance. The line wire is the best grade of galvanized iron 165 mils in diameter with a resistance per mil-foot of 69 ohms. What current flows through this line when no message is being sent?

Prob. 17. What current flows through a 40-mile telegraph line when no message is being sent, if the line wire is of second-grade galvanized iron, 203 mils in diameter and with a mil-foot resistance of 81 ohms? The battery consists of 20 cells in series, each cell having an e.m.f. of 1.06 volts and an internal resistance of 3 ohms. There are 4 relays of 50 ohms each on the line, and the return is through the ground.

123. The Telephone. Sound is heard when vibrations set up in the air strike against the ear-drum. The trans-

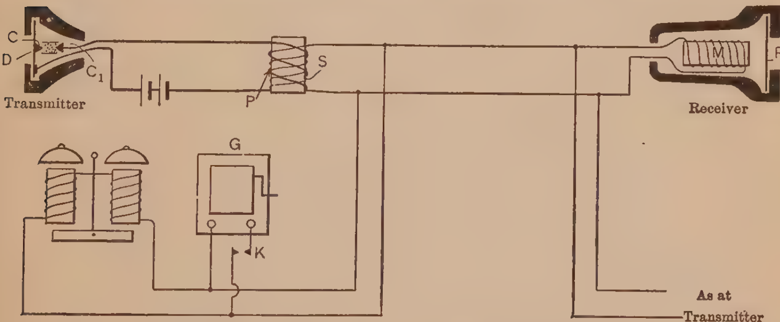


FIG. 209. Diagram of a telephone system.

mitter of a telephone system consists of a thin metal disk D (Fig. 209), to which is attached a carbon button C. Between this button and another carbon button C_1 are small particles of loose carbon. When one speaks into the transmitter, the vibrations in the air cause the disk D to vibrate very slightly, not even enough to be seen, but still enough to keep varying the pressure on the carbon particles between the buttons.

Now, when the pressure between two pieces of carbon changes, the electrical resistance between them changes, —

the more pressure, the less resistance. Thus, when one speaks into the transmitter in telephoning, the resistance of the electrical circuit containing the transmitter is changed according to the vibration of the transmitter disk, and so the current from the battery in the circuit changes according to this vibration. This makes a changing current in the primary coil P on the induction coil, and induces a much higher voltage in the secondary coil, S, as explained in connection with the induction coils used in gas-engine ignition. This induced voltage in the secondary coil sends a current through the line to the receiving station which changes in unison with the changing current in the primary coil and thus in unison with the vibration of the disk D. This current now flows through the coil on the electromagnet M in the receiver, and as the strength of this magnet keeps changing in unison with the vibration of the disk D, it keeps vibrating the disk R back and forth in unison with the disk D. By this process, the same vibrations are set up in the air by the disk R at the mouth of the receiver, as were set up in the air at the mouth of the transmitter, and the ear placed near R hears the sound as if held near the transmitter. At each station, across the receiver line, a magneto and bell are connected for signaling. When this magneto is turned, it usually automatically closes the key K, and sends an alternating current through the line. This rings all the bells attached to the line at the stations where the receivers are hung up. These bells are of the **polarized** type. That is, the armatures are permanent magnets and are repulsed and attracted alternately as the current alternates in direction, making one end of the electromagnet first north, then south. The small currents used for "talking" are not strong enough to ring these bells so they are left on the circuit all the time. Since all the bells ring when any magneto is operated, some

code of signals, as combinations of long and short rings, must be used to indicate what station is wanted. Of course each station has a transmitter, receiver, magneto, bell and induction coil.

As the wiring schemes for telephone systems are very numerous and complicated, one simple plan only is outlined. The same principles, however, underlie all the systems.

124. Railway Block Signals. For operating railway block signals, the track between two stations is divided into

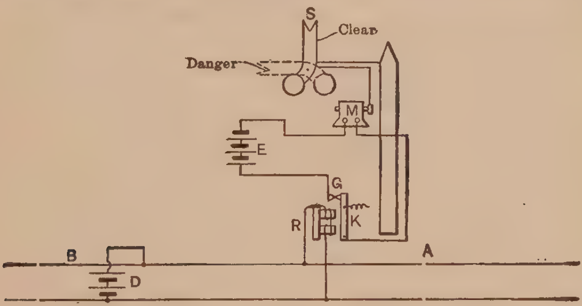


FIG. 210. Diagram of railway block signal.

several sections, called **blocks,** which are separated from one another by an insulating space, as at *A* and *B* in Fig. 210. When the block is clear, a closed-circuit battery *D* at one end of the block sends a current through the coils of a relay situated at the other end, *R*, thus keeping the armature *K* in contact at *G*. But when the wheels of a car or engine enter the block, they make a short circuit through the axle from one track to the other around the relay and steal the current from the relay. Thus the spring is allowed to pull the armature *K* over, breaking the contact at *G*. This releases magnetically the pin, which is holding the semaphore *S* in the vertical or "clear"

position, and allows a counterweight to pull it into the horizontal, or "danger," position, where it remains as long as there is a pair of wheels on the block. But when the last pair of wheels leaves the block, the battery D is again free to send a current through the relay R which pulls the armature K over and makes contact at G. The secondary battery E now drives the motor M, which is geared to the semaphore S. The semaphore is thus raised and locked at the vertical or "clear" position, and the motor automatically cut out.

Note that an **open switch** or a **broken rail** will open the circuit in which the relay is connected and set the signal at "danger." The most modern block signals are operated so that when one block is clear, but there is a train on the block ahead, the semaphore, instead of being set vertically, is set at an angle of 45°. The signal is thus at "danger" when there is a train on the block, and also when the block and the preceding block are clear of trains. The semaphore does not then become vertical, or "clear," until a train approaches it on the preceding block and both the block itself and the one ahead are empty.

125. Electric Track-switches. In Fig. 211 is shown the Cheatham track switch. It consists primarily of three elements: the **pan,** A, attached to the trolley wire about 30 feet from the switch; the **pole box,** B, containing the electromagnet (x) which makes the proper electric contact; and the **track box,** C, containing the electromagnets (1) and (2), which operate the track switch.

Note that the coil on the electromagnet (x) in the pole box is connected directly to the trolley wire at (a) and to the insulated strip (b), on the pan.

Suppose the motorman wishes to go to the **left.** He shuts off power and coasts across the pan. When the trolley

wheel strikes the pan it leaves the trolley wire and bridges the parallel strips (*b*) and (*d*), thus connecting them electrically. The current then flows from the trolley at (*a*) through the coil (*x*), to the strip (*b*), through the trolley wheel to the strip (*d*), down to arm *V*, through coil (*y*) to

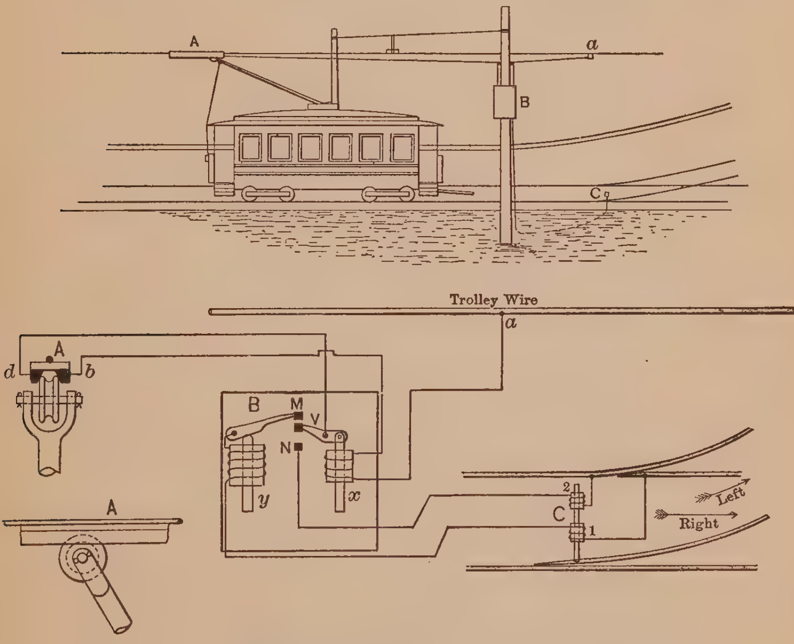


FIG. 211. Illustration and diagram of an electric track switch.

track magnet (1), and then to the ground. The total resistance of the three coils (*x*), (*y*) and (1) in this circuit is about 80 ohms. As the voltage is about 550 volts, the current must be $\frac{550}{80} = 7$ amp. (approx.). This small current has no effect upon the plunger in the coil (*x*), but is enough to actuate the plunger in the track coil (2) and set the switch to the right.

Coil (1) is not able to carry this current for more than a minute without heating. If the car should happen to stop with the trolley wheel on the pan, the coil (y) is arranged so that a plunger rises very slowly in a dash pot and breaks the contact at M, thus saving coil (1) from burning out. The coil (y) thus plays no part in setting the switch. It merely acts as a circuit breaker in case of a long-continued current through coil (1).

If the motorman wishes to go to the **right,** he throws the controller handle over two or three notches. The current then enters at (a) and goes through coil (x) to strip (b) as before. But, since the motorman has turned on the power, a current can flow from the strip (b), through the trolley wheel, through the car motor to the ground. The resistance of this path is so low that about 30 amperes flow. This current is enough to pull up the plunger in the coil (x), and trip the arm V so that it breaks the contact at M and makes a contact at N. The current now comes from the trolley at (a), goes through the coil (x) to the strip (b), crosses, by means of the trolley wheel, to the strip (d), goes to the arm V, through the contact N down to track magnet (2) and operates the plunger which sets the switch to the **right.**

During this process the coil (x) is carrying a large current, because it carries both the current which is allowed to go through the car motor and also the current which crosses over to the strip (d) and operates the switch. But as soon as the trolley wheel leaves the pan, and thus no longer bridges the strips (b) and (d), the circuit is open at this place and no current flows through the coil (x). The plunger therefore drops and sets the arm V back into contact with M, so that the next car can go either to the left or to the right. The switch, however, always remains set in the direction in which the car last passing left it.

126. The Control of Incandescent Lamps. Fig. 212 represents the ordinary wiring of a lamp when it is desired to turn it off or on from a single wall switch.

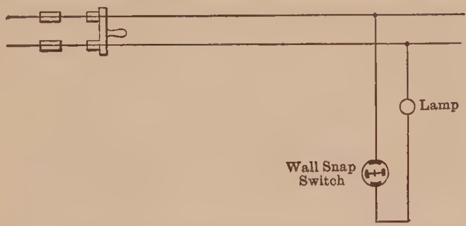


Fig. 212. The lamp is controlled from a single wall switch.

If it is desired to turn a lamp on or off at one station, as at *A*, and also at another station *B*, regardless of how the switch is set at the other station, the wiring may be done as in Fig. 213.

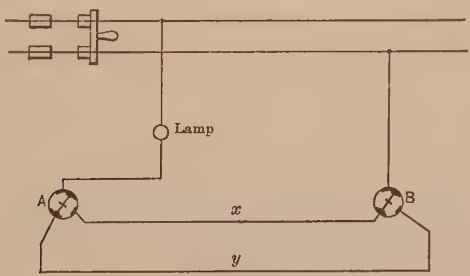


Fig. 213. The lamp may be turned off or on from either switch A or switch B.

Prob. 18. Draw the diagram of an arrangement for accomplishing the above result, except that instead of running the two extra wires, x and y, as in Fig. 213, use but one. Place the lamp in this wire, and use the same two 3-way snap switches. This method saves wire if the switches are placed near the main circuit.

Fig. 214 shows the method of control from any number of points, since any number of 4-point snap switches such

as B, C and D, can be inserted between the 3-way switches A and E if more points of control are needed.

127. Electric Signs. With the advent of the low-voltage tungsten lamp, a number of which can be used in series

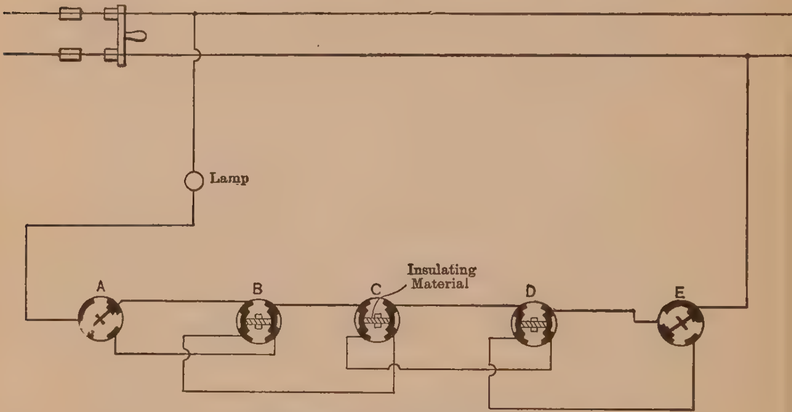


FIG. 214. The lamp may be turned off or on from any of the five points, A, B, C, D, E.

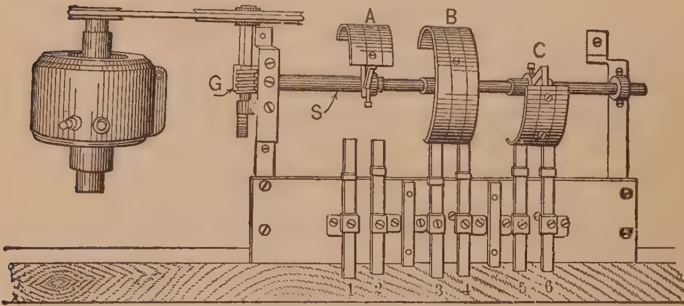


FIG. 215. Sign Flasher.

on a standard voltage line, the cost of display illumination has been greatly lowered. Consequently this branch of electric lighting has become very popular and many brilliant and striking effects are produced.

Fig. 215 shows mechanism for producing so-called **flashing signs.** By means of a motor connected through the gears *G*, the shaft *S* is made to turn slowly. The circuit through the lamps in one part of the sign is brought to the brushes (1) and (2). As the shaft turns, the brass or copper arc *A* comes momentarily into contact with these two brushes and this set of lamps flashes up. As soon as the arc *A* leaves these brushes, of course this set of lamps goes out. Similarly, other sets of lamps, connected through brushes (3) and (4) and (5) and (6), are flashed on and off by the arcs *B* and *C*. By changing the relative positions on the shaft of the arcs *A*, *B* and *C*, any desired change in the time and sequence of the flashing of each set of lamps can be made. Thus all the lamps may flash at once and go out at once. One may flash just as another goes out, or they may flash one after the other, but each set remain on until all are lighted, and then all go out at the same instant. These effects are produced merely by varying the lengths or the positions of the arcs on the shaft.

Fig. 216 shows a device for producing the latter effect.

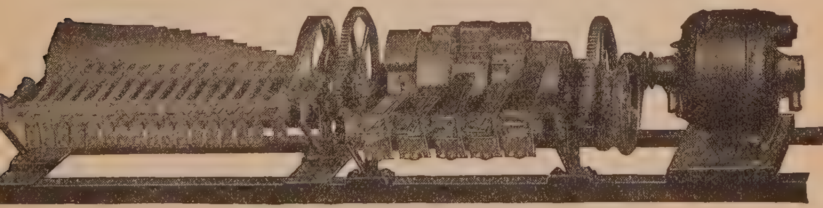


FIG. 216. Reynolds sign flasher

In this case it is combined with a device for producing other effects.

Where the effect of "**crawling snakes**" is to be produced, a similar device is used. Adjacent lamps are connected to adjacent brushes. As fast as a brush ahead touches a spiral arc, used instead of the three arcs of Fig. 216, a brush

behind leaves it; thus, a lamp ahead is turned on just as the lamp behind goes out. This gives the effect of the lighted part of the sign creeping ahead.

A most interesting device used for flashing the carriage numbers at hotel or theater entrances is shown in Fig. 217.

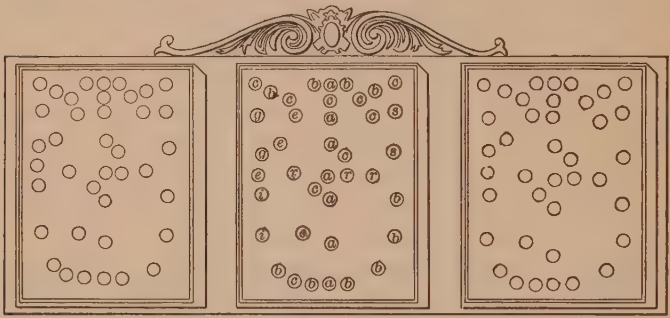


FIG. 217. Three figure electric carriage call.

The lamps labeled (*a*) are all on one circuit, those labeled (*b*) are on another, etc. By closing the proper number of circuits any figure except 2 and 5 can be flashed by the sign. For instance, if the circuit containing the lamps marked (*a*) is closed, the figure 1 is made. By closing the three circuits containing the lamps marked (*a*), (*e*) and (*r*), the figure 4 is made.

For automatically closing the proper circuit, when the switch in Fig. 218 is thrown, an ingenious device is used. Each of the several circuits in the sign ends in a metal finger for one terminal, all the circuits end in a common plate for the other terminal. In order to make the figure 1 flash, it is necessary merely to push down against the plate that finger which is the terminal of one side of the (*a*) circuit. This closes the circuit and lights up all the lamps on this circuit. In order to flash the number 4, it would be necessary merely to push down against the plate the finger

terminals of the (*a*), (*e*) and (*r*) circuits. This would close the three circuits and light up all the lamps connected to these circuits.

This is easily accomplished by placing a card, Fig. 219, having holes punched in it, between the plate and the fingers. Now when the switch is thrown, the fingers are all pressed against the card, but only those opposite the holes go through and make contact with the plate. Thus only the proper circuits are lighted.

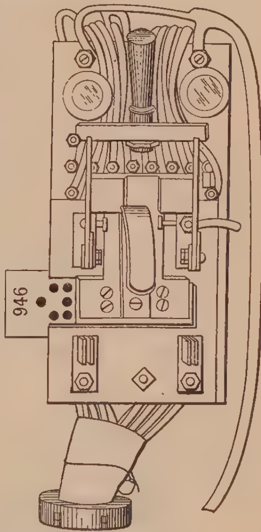


FIG. 218. Switch for lighting electric call sign.

If the card in Fig. 218, for instance, were placed in the slot between the plate and the fingers, only fingers (*b*), (*r*), (*g*) and (*s*), would make contact for circuit to the first panel and form the figure 9. The fingers (*a*), (*r*) and (*e*) of the circuit to the second panel would go through the holes in the card and form the figure 4 in that panel. In the third panel, the figure 6 would be formed by the fingers (*b*), (*g*), (*i*) and (*r*) going through the holes in the card and making contact with the plate. Thus the number 946 would show in the flasher.

Prob. 19. Draw a diagram showing the complete wiring for flashing 3 sets of lamps, one after the other. Use the apparatus shown in Fig. 215.

Prob. 20. Draw the complete wiring diagram for a "crawling snake" border consisting of 72 lamps. The "snake" must consist of 3 lamps.

Prob. 21. Draw a complete wiring diagram as in Prob. 20, using two "snakes" each consisting of 3 lamps.

Note. As the two "snakes" are in parallel, there must be only half as many flasher circuits as in Prob. 20.

Prob. 22. Show by diagram the complete wiring of one panel of the "carriage call" sign, together with the connections to the contact fingers and plate.

Prob. 23. What contact fingers must touch the plate to flash number 608?

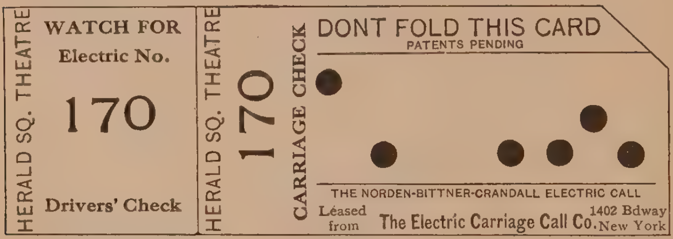


FIG. 219. Punched carriage check for electric carriage call.

128. Watt-hour Meters. As explained in Chapter IV, the instrument with which we measure the amount of electrical energy used by a customer is the watt-hour meter, illustrated in Fig. 220. It is really a small motor, the armature of which, Fig. 221, is connected in series with a resistance S, Fig. 222, directly across the line. The current in the armature then is proportional to the voltage of the line. The field coils carry the current delivered to the customer, thus the armature tends to turn with a force, or a torque, that is proportional to the watts, that is, volts $\times$ amperes.

As the friction is almost nothing, the speed would immediately rise to a dangerous value, if there were not a retarding device attached to the armature. This is in the form of an aluminum disk, shown near the bottom of Fig. 220. As the armature revolves, this disk rotates between the poles of four permanent magnets, and electric currents are

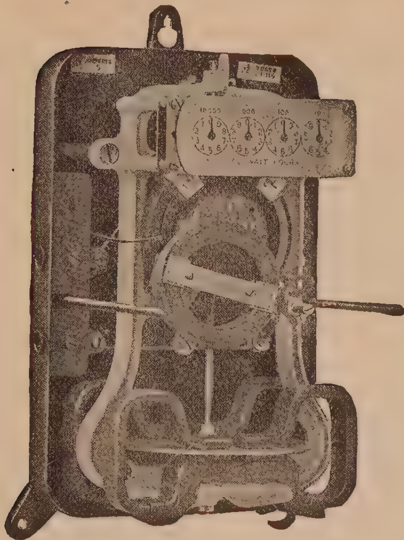


FIG. 220. Interior of G. E. Thomson watt-hour meter.

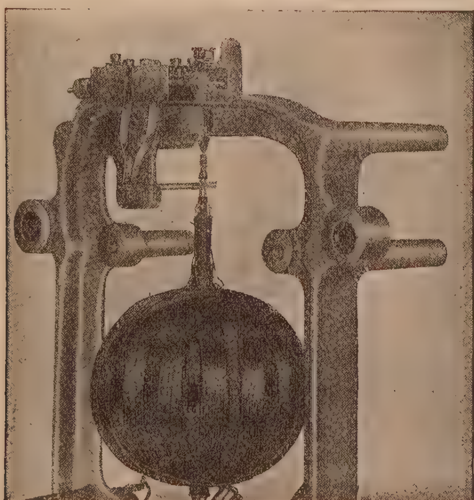


FIG. 221. Armature of the General Electric watt-hour meter.

set up in the disk because it is cutting magnetic lines. Now these currents act as a drag on the motion, and the faster the disk rotates, the greater are the currents set up, hence the greater the drag. Thus, there is always a drag equal to the torque tending to rotate the armature. The rate of rotation at any instant is then proportional to the watts being delivered. It is necessary only to gear the armature to some recording mechanism, like that shown in Fig. 220, to make it register watt-hours, or, as it is usually arranged, kilowatt-hours.

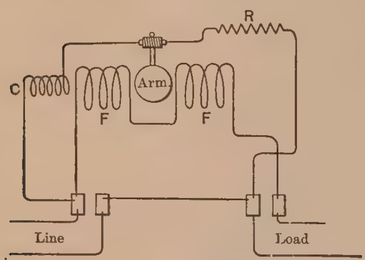


FIG. 222. Watt-hour meter connected to line to measure power consumed by a customer.

Fig. 222 shows this watt meter connected to a two-wire system. For simplicity, the aluminum disk is omitted. Note that the two field coils are in series, and that all the current taken by the customer passes through them. The armature is placed across the line. The coil C is added to increase the field enough to overcome the friction and carries a practically constant current. By moving this coil nearer to the armature, or further away, it can be made exactly to compensate for the friction.

Resistance of Soft or Annealed Copper Wire

B. & S. gauge, No.	Diameter in mils, d	Area in circular mils, d^2	Ohms per 1000 ft. at 20° C. or 68° F.	Pounds per 1000 ft.	B. & S. gauge, No.	Diameter in mils, d	Area in circular mils, d^2	Ohms per 1000 ft. at 20° C. or 68° F.	Pounds per 1000 ft.
0000	460.00	211,600	0.04893	640.5	21	28.462	810.10	12.78	2.452
000	409.64	167,810	0.06170	508.0	22	25.347	642.40	16.12	1.945
00	364.80	133,080	0.07780	402.8	23	22.571	509.45	20.32	1.542
0	324.86	105,530	0.09811	319.5	24	20.100	404.01	25.63	1.223
					25	17.900	320.40	32.31	0.9699
1	289.30	83,694	0.1237	253.3	26	15.940	254.10	40.75	0.7692
2	257.63	66,373	0.1560	200.9	27	14.195	201.50	51.38	0.6100
3	229.42	52,634	0.1967	159.3	28	12.641	159.79	64.79	0.4837
4	204.31	41,742	0.2480	126.4	29	11.257	126.72	81.70	0.3836
5	181.94	33,102	0.3128	100.2	30	10.025	100.50	103.0	0.3042
6	162.02	26,250	0.3944	79.46	31	8.928	79.70	129.9	0.2413
7	144.28	20,816	0.4973	63.02	32	7.950	63.21	163.8	0.1913
8	129.49	16,509	0.6271	49.98	33	7.080	50.13	206.6	0.1517
9	114.43	13,094	0.7908	39.63	34	6.305	39.75	260.5	0.1203
10	101.89	10,381	0.9972	31.43	35	5.615	31.52	328.4	0.0954
11	90.742	8,234.0	1.257	24.93	36	5.000	25.00	414.2	0.0757
12	80.808	6,529.9	1.586	19.77	37	4.453	19.82	522.2	0.0600
13	71.961	5,178.4	1.999	15.68	38	3.965	15.72	658.5	0.0476
14	64.084	4,106.8	2.521	12.43	39	3.531	12.47	830.4	0.0377
15	57.068	3,256.7	3.179	9.858	40	3.145	9.89	1047	0.0299
16	50.820	2,582.9	4.009	7.818					
17	45.257	2,048.2	5.055	6.200					
18	40.303	1,624.3	6.374	4.917					
19	35.890	1,288.1	8.038	3.899					
20	31.961	1,021.5	10.14	3.092					

Aluminum Wire

To find the **resistance** per 1000 ft. of a certain size aluminum wire, multiply the resistance per 1000 ft. of that size copper wire by 1.8.

To find the **weight** of 1000 ft. of a certain size aluminum wire, multiply the weight per 1000 ft. of that size copper wire by 0.30.

Resistance per Mil-foot

Material (Commercial).	Ohms per mil-foot at 20° C.
Aluminum	18.7
Copper, annealed	10.4
Copper, hard-drawn	10.65
Iron, annealed	90
Iron, E. B. B. (Roebling)	64
German silver	114 to 275
Manganin	250 to 450
IA IA (Boker) soft	283
IA IA (Boker) hard	300
Advance (Driver-Harris)	294
Nichrome	600

Average Current taken by D. C. Motors

Horse power.	Amperes on 110-volt line.	Amperes on 220-volt line.	Horse power.	Amperes on 110-volt line.	Amperes on 220-volt line.
¼	3	1.5	25	186	93
½	5.4	2.7	30	222	111
1	9	4.5	35	260	130
2	17	8.5	40	296	148
3	25	12.5	50	...	185
5	40	20	60	...	220
7½	58	29	75	...	275
10	76	38	85	...	312
15	114	57	100	...	366
20	150	75			

STANDARD SYMBOLS FOR WIRING PLANS.

(Copyrighted by the National Contractors' Association.)

Ceiling outlet; electric only. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

Ceiling outlet; combination. $\frac{4}{2}$ indicates 4-16 c-p. standard incandescent lamps and 2 gas burners. If gas only

Bracket outlet; electric only. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

Bracket outlet; combination. $\frac{4}{2}$ indicates 4-16 c-p. standard incandescent lamps and 2 gas burners. If gas only

Wall or baseboard receptacle outlet. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

Floor outlet. Numeral in center indicates number of Standard 16 c-p. incandescent lamps.

Outlet for outdoor standard or pedestal electric only. Numeral indicates number of standard 16 c-p. incandescent lamps.

Outlet for outdoor standard or pedestal; combination. $\frac{6}{6}$ indicates 6-16 c-p. standard incandescent lamps; 6 gas burners.

Drop cord outlet.

One-lamp outlet, for lamp receptacle.

Arc lamp outlet.

Special outlet for lighting, heating and power-current, as described in Specifications.

Ceiling fan outlet.

S. P. switch outlet.

D. P. switch outlets.

3-way switch outlet.

4-way switch outlet.

Automatic door switch outlet.

Electrolier switch outlet.

Show as many symbols as there are switches. Or in case of a very large group of switches, indicate number of switches by a Roman numeral, thus; S' XII; meaning 12 single pole switches.

Describe type of switch in specifications, that is, flush or surface, push button or snap.

Meter outlet.

Distribution panel.

Junction or pull box.

Motor outlet. Numeral in center indicates horsepower.

Motor control outlet.

Transformer.

Main or feeder run concealed under floor.

Main or feeder run concealed under floor above.

Main or feeder run exposed.

Branch circuit run concealed under floor.

Branch circuit run concealed under floor above.

Branch circuit run exposed.

Pole line.

Riser.

Telephone outlet; private service.

Telephone outlet; public service.

Bell outlet.

Buzzer outlet.

Push button outlet. Numeral indicates number of pushes.

Annunciator. Numeral indicates number of points.

Speaking tube.

Watchman clock outlet.

Watchman station outlet.

Master time clock outlet.

Secondary time clock outlet.

Door opener.

Special outlet for signal systems, as described in specifications.

Battery outlet.

Circuit for clock, telephone, bell or other service, run under floor, concealed. Kind of service wanted ascertained by symbol to which line connects.

Circuit for clock, telephone, bell or other service, run under floor above, concealed. Kind of service wanted ascertained by symbol to which line connects.

Heights of center of wall outlets (unless otherwise specified):	
Living Rooms	5 ft. 6 in.
Chambers	5 ft. 0 in.
Offices	6 ft. 0 in.
Corridors	6 ft. 3 in.
Height of switches (unless otherwise specified)	4 ft. 0 in.

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